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Item 8.4

Implementation Plan for the Evolution of the Global Observing System

(Submitted by the GCOS Chairman*)*

Summary and Purpose of Document

The document provides feedback on the Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP) from the GCOS Chairman

Appendix:

A. Latest version (v11.02) of the EGOS-IP with comments and some minor edits to the text made by the GCOS Chairman

ACTION PROPOSED

The Meeting is invited to note the information contained in this document.

DISCUSSION

Adrian Simmons, GCOS Chairman, submitted his comments on the recent version of the EGOS-IP (v11.02) as given in Appendix A. His comments state a bias towards Numerical Weather Prediction (the old GOS) and stress the need to cover atmospheric composition and various Essential Climate Variables (ECVs) for ocean and land in more detail. In particular, the following ECVs were not covered by the EGOS-IP:

Atmosphere:

Surface radiation budget. (mention BSRN, for instance)

Ocean:

Ocean acidity, Phytoplankton, Nutrients. (A few others only get a fleeting passing mention, but they are there.)

Land:

FAPAR, above-ground biomass, soil carbon. (Several others only get a fleeting passing mention.)

APPENDIX A

Latest Version of the EGOS-IP with comments from Adrian Simmons, GCOS Chairman

IMPLEMENTATION PLAN FOR THE EVOLUTION OF GLOBAL OBSERVING SYSTEMS (EGOS-IP)

Draft version V04	**J. Pailleux**	**12-Nov-2010**	**1st comprehensive version**
Draft version V05	**J. Pailleux**	**30-Nov-2010**	**cleaning sections 1-4, shorter, more balanced, less examples**
Draft version V06	**J. Eyre**	**01-Dec-2010**	**minor edits**
Draft version V07	**E. Charpentier**	**02-Dec-2010**	**check consistency, acronyms, etc.**
Draft version V08	**J. Pailleux**	**05-Dec-2010**	**cleaning of mistakes, mainly of references to footnotes**
Draft version V08.01	**J. Eyre**	**06-Dec-2010**	**minor edits**
Draft version V09	**J. Pailleux**	**28-Jul-2011**	**compilation of amendments from several reviewers and from the ET-EGOS members**
Draft version V10	**J.Eyre**	**23-Aug-2011**	**complete review**
Draft version V10.1	**E. Charpentier**	**31-Aug-2011**	**minor edits + clarifications + additions in section 4 per CBS decisions + actions renumbered**
Draft version V10.2	**J.Eyre**	**31-Aug-2011**	**minor edits**
Draft version V11	**J. Pailleux**	**11-Feb-2012**	**integration of comments from V10 review**
Draft version V11.01	**J.Eyre**	**23-Feb-2012**	**minor edits, and some comments for discussion**
Draft version V11.02	**J.Eyre**	**28-Feb-2012**	**minor edits from J.Pailleux, and notes on proposals from Li Bai (G11, G15)**
		4-Mar-2012	**minor edits and comments from Adrian Simmons**

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[2] GRUAN : GCOS Reference Upper-Air Network

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Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP)

1. Introduction

1.1. Preamble

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- By 2025, global observing systems will have developed considerably, building upon existing surface- and space-based sub-systems and capitalizing on existing and emerging technologies. They will be the central components of the WMO Integrated Global Observing System (WIGOS), which will provide an integrated and comprehensive system of observing systems in support of the WMO Member States' needs for information on weather, climate, water and related environmental matters. Existing components of the current WMO Global Observing System (GOS) will be interfaced with WMO co-sponsored and other, non-WMO observing systems. They will make major contributions to the Global Earth Observation System of Systems (GEOSS[3]) and to the newly created Global Framework for Climate Services (GFCS[4]). The space-based component will rely on enhanced collaboration through partnerships such as the Coordination Group for Meteorological Satellites (CGMS[5]) and the Committee on Earth Observation Satellites (CEOS[6]). Some observing sub-systems will rely on WMO partner organization systems: the Global Terrestrial Observing System (GTOS[7]), the Global Ocean Observing System (GOOS[8]) and others. Its climate components will be a major contributor to the Global Climate Observing System (GCOS[9]).

Comment [ajs1]: I added something here as I think it is necessary to say what the systems are for - i.e. what characterises a WMO observing system

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These observing systems will address the observational requirements of a wide range of application areas across all WMO and WMO-sponsored programmes, contributing to improved data, products and services from the National Meteorological and Hydrological Services (NMHSs). Although the observing systems will develop mainly by small incremental additions and technological changes, the scope of the evolution is expected to be major and to involve new approaches in science, data handling, product development and utilization, and training.

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1.2. Context

There have been very significant improvements in the WMO Global Observing System (GOS) during the recent decades. They have led to a huge improvement in the range and quality of observations available for operational meteorological activities and hence to the quality of the services that they provide.

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3 http://www.earthobservations.org/

4 In 2009, the World Climate Conference-3 (WCC-3) decided to establish a Global Framework for Climate Services (GFCS), to strengthen production, availability, delivery and application of science-based climate prediction and services. More details on: http://www.wmo.int/pages/gfcs/office/index_en.html

5 http://www.wmo.int/pages/prog/sat/CGMS/CGMS_home.html

6 http://www.ceos.org/

7 GTOS is co-sponsored by the FAO, ICSU, UNEP, UNESCO, and WMO - http://www.fao.org/gtos/

8 GOOS is co-sponsored by the ICSU, IOC of UNESCO, UNEP, and WMO - http://www.ioc-goos.org/

9 GCOS is co-sponsored by the ICSU, IOC of UNESCO, UNEP, and WMO - http://www.wmo.int/gcos

- The evolution has been particularly significant for the space-based component of the GOS, which is now a composite of many different satellite instruments and systems contributing largely to a wide range of applications.
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- In addition to playing their long-standing roles in operational meteorology and supporting rapid advances in numerical weather prediction (NWP), observations have started to support an increasingly wide range of applications, not only in real-time monitoring and forecasting of the atmosphere, but also of the oceans and the land surfaces, including in long-range forecasting at monthly and seasonal scales. User requirements have become more stringent, new requirements and new tools have appeared for these activities, models have progressed rapidly and so have their observational requirements. Altogether the observation requirements are becoming increasingly stringent and their evolution increasingly rapid.
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- The observing requirements take into account all applications within WMO sponsored and co-sponsored programmes. Some are real-time applications, including weather and ocean forecasting. For those the observations are normally exchanged and processed on time-scales from a few minutes to a few hours (depending on the observing technique, on the user requirements and on the type of dissemination). Other applications are operational but can afford longer delays for collecting and using the observations. Others are research activities which are connected to real-time applications, but are not constrained by dissemination delays. Many observation systems serve both real-time and non-real-time needs. The GCOS activities and those of the GFCS have several requirements not affected by real-time constraints, although some aspects can be considerably helped by a real-time or near-real-time exchange of data. Requirements for observations (in terms of variables measured, spatial resolution, frequency of observation, etc.) related to provision of operational climate services under the GFCS are expected to increase as the users of these services become increasingly engaged.[10] In some cases, important improvements could be obtained by simply distributing in real-time observations which are already made for other purposes.

Comment [ajs2]: Are you sure ? There may be aspects of co-sponsored programmes that do not relate to WMO interests. I would reword.

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1.3. Background and purpose of the new plan

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- Under the auspices of the WMO Commission for Basic Systems (CBS), the Open Programme Area Group (OPAG) on the Integrated Observing System (IOS) and its Expert Team on the Evolution of Global Observing Systems (ET-EGOS) guide and monitor the evolution of global observing systems. The OPAG-IOS and the ET-EGOS have set up the "Rolling Review of Requirements" (RRR) process. Under this process, requirements for observations are classified according to different application areas, and they are quantified in terms of data density (horizontal and vertical resolution), uncertainty (accuracy), observing cycle (frequency), and timeliness, for a comprehensive list of meteorological and environmental variables (wind, temperature, etc.). The RRR process regulates the management of a database containing this information, which is reviewed and updated regularly[11]. The RRR is currently conducted for 12 application areas: global NWP, high-resolution NWP, nowcasting and very short-range forecasting, seasonal to inter-annual forecasting, aeronautical meteorology, ocean applications (including marine meteorology), atmospheric chemistry, agricultural meteorology, hydrology, climate monitoring (GCOS), climate applications, and space weather. Other application areas are added as necessary. For each application area, observation requirements are compared with the capabilities of current and planned observing systems through a "critical review" by experts in the application area. The critical review is also taking into account the results from impact studies. The main deficiencies in present/planned capabilities, in relation to user requirements, are summarised in a gap analysis or "Statement of Guidance" (SoG). The user requirements, the assessment of current and planned capabilities and the SoGs are the primary inputs which have contributed firstly to the "Vision for the

Comment [ajs3]: I would delete the reference to GCOS. Otherwise, you need to add a lot more acronyms here for balance.

[10] Users of climate services in the context of the GFCS are a broad and highly diverse group including policymakers, managers, engineers, researchers, students and the public at large, in all sectors and socio-economic systems (including agriculture, water, health, construction, disaster risk reduction, environment, tourism, transportation, etc), and the full extent of their requirements is not yet known.

[11] See http://www.wmo.int/pages/prog/sat/Databases.html#UserRequirements

GOS in 2025" and now to the analysis and Actions in this Implementation Plan. A description of the RRR process and SoGs in their most recent versions can be accessed on the WMO web site[12].

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- The first version of EGOS-IP was developed during the period 2001-2003 and adopted by CBS in 2005. It contained a set of recommendations aimed at improving both the surface and space-based sub-systems of the GOS. This new plan is the result of a complete rewriting of the old plan. The rewriting has been necessary for the following reasons:

- From 2003, many comments and updates have been added on the top of the original recommendations, as part of the process of reporting progress on the EGOS-IP. These comments and updates are now mainly of historical interest and make the document difficult to read.
- Some recommendations are out-of-date.
- Some new recommendations have been added in the progress report, and many of these are still relevant to the new EGOS-IP.
- The "Vision for the GOS in 2025"[13], which was initiated by ET-EGOS in 2007 and adopted in 2009 by the Sixty-First WMO Executive Council (EC-LXI), provides high-level goals for the evolution of observing systems. The new EGOS-IP is a comprehensive response to the new Vision and mirrors it in structure. WIGOS provides a new organisational framework for WMO observing systems, and it is necessary to place EGOS-IP within this framework and to include elements that are important within WIGOS, such as integration and interoperability.
- The new EGOS-IP is more specific concerning who has to take the different implementation Actions, as well as about the governance, monitoring and quality assurance of the Actions.
- The new EGOS-IP responds to the new version of the Implementation Plan for the Global Climate Observing System (GCOS-IP)[14], and emerging requirements of the GFCS, and the Global Cryosphere Watch (GCW). In this Plan, Actions are included to emphasise and propagate GCOS requirements for high-quality observations of Essential Climate Variables (ECVs) and the standards of observation set out in the GCOS Climate Monitoring Principles (GCMPs).

Comment [ajs4]: GAW is conspicuous by its absence here, and elsewhere in the text.

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- The purpose of the present EGOS-IP is to document a set of implementation Actions which are important for incremental improvement of global observing systems and for a convergence towards the 2025 Vision. Many of the Actions from the old version of the plan are reiterated and updated. In addition, the new Plan identifies the actors (organizations, bodies) who are responsible of each Action, the expected time-frame, the overall management and monitoring, as well as performance indicators. The performance indicators often refer to "number of observations" or " number of observing systems". Although not specified for each individual Action, these figures should be read as, e.g., number of observations of acceptable quality, and it is envisaged that the WMO Quality Management Framework (QMF), as applied to instruments and observation methods[15], will play an important role here (see section 2.1).

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- The new EGOS-IP describes the implementation Actions as they are envisaged in the early part of the decade 2010-2020, and it covers the period up to 2025. To monitor the Actions in this Implementation Plan, a progress report will be made regularly; it will describe the progress using this baseline EGOS-IP as reference.

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- When the planned activities appear sufficient to meet the requirements by 2025, no Action is included in the corresponding sub-section. However, this does not preclude the addition of further Actions at a later date, if monitoring of progress on this Plan shows that the plans of implementing agents have changed and a "gap" has emerged.

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[12] http://www.wmo.int/pages/prog/sat/RRR-and-SOG.html#SOG
[13] See http://www.wmo.ch/pages/prog/www/OSY/WorkingStructure/documents/CBS-2009_Vision-GOS-2025.pdf
[14] See http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

[15] See http://www.wmo.int/pages/prog/amp/QMF-Web/Documentation/Other/InstrumentsMethodsObs.pdf

- Section 3 in this Plan deals with cross cutting Actions, and section 4 addresses special considerations in relation to developing countries. Actions are then documented separately for each observing system - for the surface-based observing systems in section 5, and the space-based observing systems in section 6.

2. The strategic approach to implementation

2.1. Overall approach and relationship to WIGOS

- The present plan contains implementation Actions aimed at observing many variables describing the atmosphere and the environment in contact with the atmosphere (ocean, ice and land). It is intended that these Actions are challenging but feasible in the time-frame 2012-2025, although they may not be completed by 2025. These Actions are derived to a large extent from the gap analyses provided by the RRR process. The priority of the different actions is guided by the RRR in different application areas and by the corresponding SoGs.

Comment [ajs5]: I think "by" conveys the intended meaning better.

- The development of these Actions has been informed by a range of information, not only on the gaps between existing/planned observing capabilities and currently-stated user requirements, but also on the most cost-effective ways to fill these gaps. Where possible, guidance has been taken from experiments on the impact of real or hypothetical changes to observing systems. In particular, the results of Observing System Experiments (OSEs), Observing System Simulation Experiments (OSSEs) and other types of impact study performed by NWP centres have been taken into account.

Comment [ajs6]: NWP is not the only application served by the WIGOS, so I think this paragraph has to be qualified by some further text on this point.

- The EGOS-IP Actions specified by this plan take into account the WIGOS vision, requirements, objectives and scope, specified by the WIGOS Development and Implementation Strategy (WDIS), adopted by Cg-XVI (2011)[16]:

WIGOS Vision and requirements.

- The WIGOS Vision calls for an integrated, coordinated and comprehensive observing system to satisfy, in a cost-effective and sustained manner, the evolving observing requirements of WMO Members in delivering their weather, climate, water and related environmental services. WIGOS will provide a framework for enabling the integration and optimized evolution of WMO observing systems, and WMO's contribution to co-sponsored systems.

- To enable improved service delivery, there is a need to improve the existing observing capabilities, make them more cost-effective and sustain their operation. To ensure a coordinated, comprehensive, and sustainable system that meets the requirements of WMO and partners, improved governance, management, and integration of observing systems is needed.

- Integration must be pursued to ensure interoperability and facilitate optimization across observing components. A principal requirement for integration is the standardization in three key areas: Instruments and Methods of Observation; WMO Information System (WIS) information exchange and discovery; and the QMF.

Quality Management Framework (QMF).

- WIGOS is expected to provide timely, quality-assured, quality-controlled and well-documented long-term observations. Implementing Quality Management procedures is required to enable better utilization of existing and emerging observing capabilities.

- WIGOS will address high-level observing requirements by establishing the effective and sustained organizational, programmatic, governance and procedural structures. These structures

[16] See http://www.wmo.int/wigos

will enable a common standardization approach, uniform implementation of WMO regulations, data compatibility and interoperability across all WIGOS observing components. It will also provide a single focus for integrated and coordinated operational management of all WMO observing systems and a mechanism for coordination with WMO co-sponsored and contributing observing systems.

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- WIGOS will embrace QMF procedures to ensure that observations, records and reports on weather, water, climate and other environmental resources, operational forecasts, warnings, related information and services are of identified quality, and in compliance with relevant joint standards agreed upon with other international organizations.

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- This should be based on agreed-upon quality assurance and quality control standards, with the goals of developing and implementing an integrated Quality Management System (QMS); in doing this, and only after effective national implementation, it will deliver reliable and timely data streams with adequate quality control and relevant metadata.

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- **Coordinated Planning and Optimizing of Observing Systems.**

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- Within the WIGOS framework, this will be performed through the RRR process, as described in section 1.3.

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- The development of WIGOS will draw benefits from various pilot projects which are expected to help the long-term development of global observing systems.

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- The EGOS-IP describes the implementation Actions proposed to Members and partner agencies for each observing system. Other aspects of WIGOS - the management of networks, the relationships with partner organizations, coordination with WIS, etc. – whilst important, are outside the scope of EGOS-IP.

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- Several elements of the EGOS-IP strategic approach are also shared by the strategic approach of the GCOS-IP. These elements of the strategy are the following:

- Global coverage of surface-based in-situ and remote sensing observing networks. This largely involves improvements in existing networks to achieve the recommended technical, operational and maintenance standards, especially in developing countries, for the atmosphere, oceans, cryosphere and the continental surfaces.
- Expansion of existing networks and especially improvement of the density and frequency of observations for data-sparse regions, such as the oceans, the tropics and the high latitudes and altitudes, and to meet the emerging requirements of GFCS user communities.
- Improved data acquisition systems and data management procedures, keeping consistency with the WIS and WIGOS concepts; this includes an adherence to internationally accepted standards for weather, climate, water and related environmental observations, and associated data exchange.
- Effective utilization of satellite data through continuous and improved calibration and/or validation, effective data management, and continuity of current high-priority satellite observations.
- Enhanced monitoring of data availability and quality (at all the stages of the processing, exchange and use) based on existing data systems.
- Continued generation of new capabilities through research, technical development and pilot-project demonstration.

Comment [ajs7]: Cryosphere is out of place here. It's part of the oceanic and terrestrial domains. If you mention cryosphere, why not biosphere, hydrosphere, …?

Comment [ajs8]: It's more than the continental surfaces. Ground water for example.

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- 2.2. Agents for implementation

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- For the surface-based observing systems the implementation Actions rely mainly on national agencies such as NMHSs, although in several cases, in-situ observing networks are implemented by non-meteorological institutes or agencies in the context of an international programme or within a strong international cooperation. In some cases the networks are funded for research purposes and their sustainability is therefore a concern.

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- For the space-based observing systems, the agents are sometimes national space agencies operating satellites for research and/or operational purposes, and sometimes some multi-national agencies which are specialized in space observations.

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- For both surface and space-based systems, the level of international cooperation needed is high, justifying the existence of several international programmes sponsored or co-sponsored by WMO in partnership with other international organizations. For observing systems evolving from research to operational status, three WMO Technical Commissions (TC) have a leading role: the Commission for Basic Systems (CBS), the Commission for Atmospheric Sciences (CAS) and the Commission for Instruments and Methods of Observation (CIMO).

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- For land-based in-situ observing networks, the design and development is often carried out through Regional Associations (RAs) which have a key coordination role in their respective regions, in collaboration with WMO TCs), primarily (but not only) CBS. Concerning ocean in-situ observing networks, the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) is involved for all the observing systems making marine meteorological measurements at the surface, as well as oceanographic measurements at the ocean surface or at depth. For space-based observing systems, the role of RAs is less important because of the general tendency of the satellite observation to be global and less regional than in-situ observing networks. But the role of WMO is equally important, and WMO works in close cooperation with the Coordinating Group for Meteorological Satellites (CGMS) and with the space agencies.

Comment [ajs9]: Something on the terrestrial side is needed here - e.g. reference to GTOS.

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3. Over-arching and cross-cutting Actions

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- This section of the Implementation Plan follows closely the description of the general trends and issues, as they are documented in the "Vision for the GOS in 2025", and develops the general Actions which are necessarily associated with these trends and issues.

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- 3.1. Response to user needs

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Global observing systems will provide comprehensive observations in response to the needs of all WMO Members and Programmes for improved data, products and services, for weather, water, climate and related environmental matters. Through WIGOS, WMO will continue to provide effective global collaboration in the making and dissemination of observations, through a composite and increasingly complementary system of observing systems.

The sustainability of these observing systems may require partnerships between research and operational agencies. Observations of several variables are made in the context of research programmes or by space agencies whose primary mission is research and development. Once methods are sufficiently mature to guarantee a sustained set of observations to an acceptable level of accuracy, they need to be sustained into the future as an operational observing system if they fulfil the requirements of some user groups.

The operational system includes the acquisition (measurement), the transmission to a pre-processing centre, and archiving and dissemination to all the users with a procedure which is compatible with the WIS. These activities may or may not imply a transfer of responsibility from one organization to another. Whenever new or upgraded observing technologies or data processing systems are developed it is essential that there be interaction between the developers, the intermediate and end users to assess requirements and the impact of the new or evolving system before implementation. This will help ensure that all essential requirements are captured, including requirements for homogeneity of observations in time.

Comment [ajs10]: "acquisition" is not a good word to use here. It is also used in the context of acquiring data from archives.

- **Action C1**

- **Action**: Set up a development scheme for sustained operation of relevant research-based observing systems, once their validation has shown they are sufficiently mature enough and their cost-effectiveness has been assessed.
- **Who**: CBS and CAS to initiate and lead the evolution, with all organizations operating component observing systems.
- **Time-frame**: Continuous. Timetable to be decided on a case by case basis.
- **Performance indicator**: Number of sustained systems.

Comment [ajs11]: Bit vague. How will sustained be defined?

- **Action C2**

- **Action**: Ensure all operators producing observations are encouraged to adhere to the WIS standards[17].
- **Who**: Organizations and agencies operating observing programmes. Action monitored by CBS.
- **Time-frame**: Continuous.
- **Performance**: Extent to which WIS standards are applied.

Action C3

Action: Assess the impact of new observing systems (or changes to existing systems) through prior and ongoing consultation with data users and the wider user community.
Who: CBS and CAS to lead the action, together with other TCs and co-sponsored programmes representing the users and all organizations operating component observing systems.
Time-Frame: Continuous.
Performance Indicator: Extent to which user community concerns are captured.

Comment [ajs12]: GCOS and WCRP, for example

- Large parts of marine and ocean observing systems are currently maintained by research funding with limited duration. Considering the importance of continuous, long-term observations for key marine/ocean variables for many applications, including medium-range weather and seasonal climate forecasting, WMO Members should note potential gaps that may occur at the end of these research programmes unless ongoing funding for sustained observing networks is guaranteed. Such observing networks include (i) the tropical moored arrays, (ii) Argo, (iii) a fraction of barometer upgrades on surface drifters (for weather forecasting), and (iv) altimeter, scatterometer, microwave sea surface temperature (SST) and sea ice measurements from research satellite missions.

Comment [ajs13]: Missions may not be solely for the ocean, as the instruments may provide land information also.

- **Action C4**

- **Action**: Ensure sustained funding for the key marine/ocean observing systems (e.g. tropical moorings, Argo, surface drifters with barometers, as well as altimeter, scatterometer, microwave SST, sea ice measurements from research satellite missions). **Who**: NMSs, NMHSs and partner national institutions, in collaboration with international organizations, WMO TCs responsible for observing system coordination (e.g. JCOMM, CBS, and CIMO).
- **Time-scale**: Continuous
- **Performance Indicator**: Percentage of observing networks funded through sustained mechanism.

- Users require global observing systems to provide observations when and where they are needed in a reliable, stable, sustained and cost-effective manner. They require observations of specified spatial and temporal resolution, accuracy and timeliness. The user requirements will evolve in response to a rapidly changing user and technological environment, based on improved scientific understanding and advances in observational and data-processing technologies. Our ability to measure some key environmental variables is often limited by the lack of suitable techniques. These limitations can vary from the fundamental underlying observing technique to those associated with instrumentation, data processing, suitable calibration/validation techniques,

[17] See http://www.wmo.int/pages/prog/wis/

spatial and/or temporal resolution, ease of operation, and cost. As new remotely-sensed observations of environmental variables are made, it is critically important that the validation of both the measurements themselves and the retrieval methods used are carried out under a sufficient broad range of geophysical conditions. It is also important to derive observational products in a physically consistent way across ocean, land and atmosphere domains. The development of integrated products requires blending of different datasets or data sources, which needs to be consistent over time and space.

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Some level of targeted observations will be achieved, whereby some observations are made or not made, in response to the local meteorological situation and the particular user needs. Their operation should be guided by and in collaboration with NMHSs to ensure interoperability and potential exchange of the data (see also section 5.3.1.1.5).

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- **Action C5**
    - **Action**: For each relevant observing system, investigate the feasibility, cost-effectiveness and side effects on the continuity of climate data records of operating it in an adaptive mode, i.e. a process which would vary the observation set according to the meteorological situation.
    - **Who**: Organizations operating observing networks on a routine basis. Process to be initiated and coordinated by CAS in cooperation with other TCs, mainly CBS and CIMO.
    - **Time-frame**: Continuous reviewing process of the feasibility and cost-effectiveness assessments.

    Performance indicator: Number of networks operated with some level of targeting.

Comment [j14]: How do we ensure CAS buy-in to this Action?

Comment [ajs15]: This has implications for climate. WCRP, CCl and GCOS merit a mention here

3.2. Integration

The GOS will become a core observing component of the WIGOS, which will integrate current GOS functionalities (which have been developed primarily to support operational weather forecasting) with those of other applications, including climate monitoring and operational climate services. Integration will be developed through the analysis of requirements and, where appropriate, through sharing observational infrastructure, platforms and sensors, across systems and with WMO Members and other partners. Surface and space-based observing systems will be planned in a coordinated manner to serve a variety of user needs with appropriate spatial and temporal resolutions in a cost-effective manner.

Comment [ajs16]: Could mention GAW here also. I am concerned that WIGOS will be the GOS plus the rest handled at lower priority as an afterthought.

Data assimilation techniques have an important role to play with respect to a cost-effective integration of the different observing systems serving different applications across different disciplines. Data assimilation techniques are indeed able to add considerable value to observing systems by combining heterogeneous sets of information to provide complete and self-consistent sets of geophysical fields. Taken on its own, each observing system provides only a small sample of information with respect to the ensemble of global requirements as they are documented by the RRR process. However, combined in a global assimilation, the integration of their measurements is able to provide reliable global analyses for many variables, which are essential for many global applications.

For the achievement of this Implementation Plan, an important challenge is to find means for maintaining the long-term operation and the continuity of these observing systems. This does not mean that the continuity of each system should be guaranteed indefinitely; the strategy consists in making sure that the quality of the important variables is not degraded when an instrument or an observing system is replaced by another instrument or another observing system. Several applications use observations which are labelled “research” or “demonstration” for operational purposes. The border between “research” and “operations” is not well-defined and is moving all the time, mainly because it follows the scientific progress in applications and in data utilization methods. In this context, ensuring that observations of important variables are not degraded may mean ensuring the transition of research/demonstration systems into operational systems (which is recognized to be very challenging).

-
- The integrating role of WIGOS is also supported by the strong complementarity between surface-based and space-based observations. Some examples:

- For observing the atmosphere, surface-based systems are more efficient in the boundary layer whereas satellite instruments are more efficient in the stratosphere and above the clouds.
- High horizontal resolution can be obtained with space-based imagers and sounders with global data coverage; this is impossible to achieve with in-situ observing networks which remain the best systems for high vertical resolution, especially in the lower atmosphere.
- The most accurate SST fields are obtained from a combination of satellite retrievals mixed with in-situ reference measurements.

Comment [ajs17]: Should include that satellites provide valuable information on terrestrial (land) conditions

-
- Observations should be made available to the different users with a timeliness respecting their requirements. They should also be made available using standard practices for data processing, coding formats and dissemination, in order to facilitate the utilization.

-
- **Action C6**
  - **Action**: Ensure time continuity and overlap of key components of the observing system and their data records, in accordance with user requirements, through appropriate change-management procedures.
  - **Who**: WMO TCs, JCOMM, regional associations, satellite agencies, NMSs and NMHSs, all organizations operating observing systems.
  - **Time-frame**: Continuous. Timetable to be decided on a case by case basis.
  - **Performance indicator**: Continuity and consistency of data records.

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3.3 Data policy

The operating paradigm for the GOS is built on WMO data sharing principles under which all essential data are shared openly among the WMO members. This has been facilitated by the fact that, in the past, observational data have been provided primarily by national governments and international agencies. However, the potential for an increased role in the future for commercial entities - e.g. hosting of instrument payloads or "data buys" and similar mechanisms - raises important issues regarding the continued availability to all WMO members of data obtained under such arrangements.

Comment [ajs18]: GAW is rather less so, but it is a part of WIGOS. It needs mentioning here. One of the benefits of a well-implemented WIGOS should be an increasing availability of NRT GAW data.

- **Action C7**
  - **Action**: For new observing systems, including satellite systems, ensure continued adherence to WMO data sharing principles irrespective of origin of data, including data provided by commercial entities.
  - **Who**: NMSs and NMHSs, and space agencies. Process monitored by CBS.
  - **Time-frame**: Continuous.
  - **Performance indicator**: Continued availability of all essential observational data to all WMO members.

-

3.4. Expansion

There will be an expansion in both the user applications served and the variables observed. This will include observations to support the production of datasets related to the GCOS essential climate variables (ECVs), adhering to the GCOS climate monitoring principles, and any additional observations required to implement operational climate services at global, regional and national scales under the GFCS. Atmospheric chemistry and hydrology are also two application types requiring an increasing number of variables to be observed.

The range and volume of observations exchanged globally (rather than locally) will be increased. Several existing local observing systems are currently used only for local or regional applications; they will be used also in global applications as soon as they have proved they are able to bring additional value. The total volume of global data exchange will expand considerably because of new observed variables, because of existing local observations becoming exchanged globally, and because of increased resolutions (time and space) of global observing systems. The role of satellite and radar data sets will expand into applications requiring higher and higher horizontal resolution. This implies that the specialized data centres will have to serve a wider range of applications at all horizontal scales, from global to hectometre scale. This data volume expansion puts heavy constraints on the data processing and dissemination processes which will be operated according to the WIS standards (especially important for real-time applications).

- **Action C8**
  - **Action**: To evaluate the future evolution of data volumes to be exchanged and handled, based on the projected data volumes generated by the future satellite and terrestrial sources.
  - **Who**: WMO TCs (led by WMO/WIS), JCOMM, regional associations, satellite agencies, NMSs and NMHSs, all organizations operating observing systems.
  - **Time-frame**: Continuous.
  - **Performance indicator**: evolution of the data volumes handled and exchanged.

Comment [ajs19]: Terrestrial is used to mean land in our business - e.g. its appearance in GTOS. Another word or words - surface-based and airborne, for example - should be used.

3.5. Automation

The trend to develop fully automatic observing systems, using new observing and information technologies will continue, where it can be shown to be cost-effective and does not lead to degradation in respect of important requirements of some applications, e.g. climate monitoring. The access to real-time and raw data will be improved. More and more observing systems will have to produce different levels of data, from large volumes of raw data to highly processed data sets. A variety of users will be interested in one or more post-processing levels. It is important to have the different processing packages respecting a general set of WIS standards. Observational data will be collected and transmitted in digital forms, highly compressed where necessary. Data processing will be highly computerized.

A high degree of automation (with minimal checking to ensure observation quality) is especially required for observational networks covering areas highly exposed to severe weather phenomena. For nowcasting and risk mitigation in these areas, it is important to have a telecommunication infrastructure that is robust enough against these phenomena.

Comment [ajs20]: Not sure why this is here. There can be automated QC.

3.6. Interoperability, data compatibility, consistency and homogeneity

There will be an increased standardization of instruments and observing methods. There will be improvements in calibration of observations and the provision of metadata, to ensure data consistency and traceability to absolute standards. There will be an improved homogeneity of data formats and dissemination via the WIS, and also increased interoperability, between existing observing systems and with newly implemented systems. Metadata are essential for ensuring the quality, traceability and homogeneity of observations, therefore it is essential that an archive of rigorous metadata is maintained to support standardization, enable homogeneity assessments, and ensure data provenance and fitness for purpose.

Comment [ajs21]: Are you sure? The US not supplying MW instrument for post-EPS is a step in the other direction.

-

To ensure consistency and homogeneity of the data sets, the monitoring principles for satellite data which are documented in the GCOS-IP for climatological purposes are all valid to some extent for other WMO applications, including the real-time applications. This is true for the recommendations which concern the time continuity, homogeneity and overlap of the observation, the orbit stability and sensor calibration, the data interpretation, processing and archiving. Global analyses for weather forecasting and other applications are dependent on several key observing systems. The long-term time continuity of these sensors is obviously very important for climate purposes, but it is almost as important for the other applications, including the real-time ones. All these sensors are used in a “synergetic” way, e.g. where one sensor helps in the evaluation of biases and drifts in other sensors. In this process the role of accurate in-situ observations is also important, supporting the GCOS requirements for the GCOS Reference Upper Air Network (GRUAN).

By 2025 there will be improved methods of quality control and characterization of errors of all observations. Operational systems are needed that can track, identify and notify network managers and operators of observation irregularities, including time-dependent biases, as close to real-time as possible. Such feedback systems are already routine practices for several NWP centres, for the data which are assimilated in operational NWP models, and also for climate monitoring centres to ensure overall data quality. However there is a need to extend these monitoring activities to other applications and also to set up feed-back procedures for observed quantities which cannot be compared to any operational model. Also, even in the existing routine monitoring activities, there is a need to make more rapid and more efficient both the feedbacks to the operators and the correcting actions.

- **Action C9**
  - **Action**: Monitor the flow of all essential data to processing centres and to users and ensure timely flow of feedback information to observing network management from monitoring centres.
  - **Who**: Data processing centres coordinated by appropriate TCs and international programmes (CBS to lead the process and initiate it when required).
  - **Time-frame**: Continuous
  - **Performance indicator**: usual monitoring criteria[18]
  -

3.7. Radio-frequency requirements

WIGOS components make use of a number of different radio applications.

Space-based passive sensing is performed in bands allocated to the Earth exploration satellite (passive) and meteorological satellite service. Passive sensing requires the measurement of naturally occurring radiation, usually of very low power levels and containing essential information on the physical process under investigation.

The relevant frequency bands are determined by fixed physical properties (molecular resonances) that cannot be changed or ignored. These frequency bands are, therefore, an important natural resource. Even low levels of interference received by a passive sensor may degrade its data. In addition, in most cases these sensors are not able to discriminate between natural and man-made radiation. In this respect, the International Telecommunication Union (ITU) Radio Regulations enable the passive services to deploy and operate their systems in the most critical frequency bands.

Several geophysical variables contribute, at varying levels, to natural emissions, which can be observed at a given frequency with unique properties. Therefore, measurements at several frequencies in the microwave spectrum must be made simultaneously in order to extract estimates of the variables of interest from the given set of measurements. Passive frequency bands should hence be considered as a complete system. Current scientific and meteorological satellite payloads are not dedicated to one given band but include many different instruments performing measurements in the entire set of passive bands. Also, full global data coverage is of particular importance for most weather, water and climate applications and services.

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[18] Http://www.wmo.int/pages/prog/www/ois/monitor/introduction.html

Also of great importance is the availability of sufficient and well-protected Earth exploration and meteorological satellite frequency spectrum for telemetry / telecommand, as well as for satellite downlink of the collected data.

The meteorological aids (MetAids) radiocommunication service is used for meteorological and hydrological observations and exploration, and provides the link between an in-situ sensing system (e.g. a radiosonde) for meteorological variables and a remote base station. The base station may be in a fixed location, or mounted on a mobile platform. Additionally, meteorological radars and wind profiling radars provide important observations. There are currently about 100 wind profiler radars and several hundred meteorological radars world-wide, which provide precipitation and wind information and play a crucial role in meteorological and hydrological alert processes.

The issues related to the above radio spectrum requirements and operation are addressed within WMO by the Steering Group on Radio Frequency Coordination (WMO SG-RFC). Within Europe, more than 20 National Meteorological Services and other relevant organizations have established the EUMETFREQ programme in order to coordinate their frequency protection activities. Frequency management and protection are particularly important for the WMO Space Programme and Space Agencies have established the Space Frequency Coordination Group (SFCG[19]) to coordinate their activities in this respect.

- **Action C10**
  - **Action**: Ensure a continuous monitoring of the radio frequencies which are needed for the different components of WIGOS, in order to make sure they are protected against other utilizations.
  - **Who**: WMO / SG-RFC in coordination with NMSs, NMHSs and national organizations in charge of radio frequency management.
  - **Time-frame**: Continuous
  - **Performance indicator:** observation frequency bands protected / not protected.

4. Considerations for the evolution of observing systems in developing countries

- Many developing countries and countries with economies in transition do not have the capabilities or the resources to provide the essential in-situ observations. This is a challenge for the consistency and the homogeneity of observations, especially at the global scale. The support needed by these countries and the mechanisms able to provide this support are the same as those described in the GCOS-IP (see its section on developing countries) for climate purposes, plus some support often needed to disseminate in real-time observations which are already made, in the proper format to the WIS.

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More effort is needed to support these countries, especially Least Developing Countries (LDCs) and Small Islands Developing States (SIDSs), by providing guidelines and organizing training and capacity-building events in the respective Regions. In many areas, including large parts of Africa, Asia and Latin America (Regions I, II, and III and some tropical areas between 25N and 25S), the current GOS provides very few observations. The evolution of observing systems in developing countries must address issues that fall in three categories: (a) lack of public infrastructure such as electricity, telecommunication, transport facilities, etc.; (b) lack of expertise from people to do the job, training, etc.; and (c) lack of funding for equipment, consumables, spare parts, manpower, etc. The lack of infrastructure and expertise may be the result of a lack of funding.

Comment [ajs22]: This is a bit strong.

Evolution of observing systems must take into account upgrading, restoring, substitution and capacity building (especially in the use of new technologies). Two aspects need to be considered:

[19] See http://www.sfcgonline.org/home.aspx

the data production and the data use. It is possible that some countries do not and will not be able to produce data and will therefore only be users of data. To help developing countries produce data for international exchange, due consideration must be given to the three issues previously identified i.e. public infrastructure, expertise and funding.

Possible approaches to observing system evolution in these conditions are the following. A first step should be to identify observing systems that are less dependent on local infrastructure. Where local infrastructures are sufficient or can be externally supported, it may be possible to augment in-situ observations with other technologies such as satellite data, AMDAR, dropsondes, and Automatic Weather Stations (AWS).

A minimum set of reliable radiosondes is required as a backbone to the GCOS Upper Air Network (GUAN). NWP impact studies[20] have shown the prominent importance of isolated radiosonde observations for both global and high resolution NWP.

Obtaining vertical profiles (of wind, temperature and, in the near future, humidity) by AMDAR in many data sparse areas appears as a natural way to obtain observations of some basic atmospheric variables in some countries with important airports and very few conventional atmospheric observations.

Comment [ajs23]: IAGOS gets a mention quite a bit later, but could be flagged a bit earlier, as there is an awful lot on AMDAR.

This section seems to be another GAW-free zone, though perhaps I have missed something.

Capacity building in some countries continues to need attention. International responsibilities for data exchange may be supported by the migration toward the table-driven codes (BUFR[21] or CREX[22]) as a reliable representation of the data. More importantly, it will be necessary to develop and deploy systems for automatically generating messages (such as CLIMAT reports) and to ensure timely, efficient and quality-controlled flow of essential data, in keeping with the WIS implementation strategy.

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Some countries have satellite receiving stations or receive satellite data through the Global Telecommunication System (GTS), but lack the expertise to utilize the information to their benefit. Some countries are acquiring Doppler radar but need training on how to process and interpret the information. For example, Region I has benefited with expanded access to conventional data and satellite imagery through the Préparation à l'Utilisation de MSG en Afrique (PUMA) project. This type of project should be expanded to include other data types for routine application (synoptic meteorology, aviation, nowcasting).

The following guidelines are proposed for the allocation of priorities for technical cooperation activities for the integrated observing systems:

(a) Highest priority should be given to the projects aiming at improving and restoring the existing, and building the new upper-air observational capabilities, of the RBSN[23]/RBCN with emphasis to the activation of silent upper-air stations and the improvement of coverage over data-sparse areas (in particular as regards the purchase of equipment and consumables, telecommunications and the training of staff);

(b) Highest priority should be given to extend AMDAR coverage to developing countries, LDCs and SIDS to supplement scarce upper-air observations or to provide a cost-effective alternative to countries that cannot afford costly upper-air sounding systems;

(c) High priority should be given to the projects related to the improvement of data quality, regularity and coverage of surface observations of the RBSN/RBCN with emphasis to the activation of silent stations and the improvement of coverage over data-sparse areas;

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[20] See http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-4_Geneva2008_index.html

[21] FM 94 BUFR Global Telecommunication System (GTS) format - Binary universal form for the representation of meteorological data

[22] FM 95 CREX GTS format - Character form for the representation and exchange of data

[23] GCOS Surface Network (GSN) and GUAN stations are part of the RBSN (Regional Basic Synoptic Network)

(d) High priority should be given to projects related to the introduction and/or use of new observing equipment and systems including, where cost-effective, surface-based AWSs, AMDAR, ASAP and drifting buoys;

Comment [ajs24]: Two highest and two high, but with AMDAR appearing both with highest and high priority. Could we have just one highest priority?

Finally, the following recommendations should be taken into account when addressing the evolution of observing systems in developing countries:

- Define geographical areas to which priority for additional observations should be given, if additional funding were available.
- Prioritize where the needs are most pressing for WMO Voluntary Cooperation Programme (VCP) or other funding.
- Give high priority, in the Regions and the Secretariat, to maintaining a minimum radiosonde network with acceptable performance within data-challenged regions.

Comment [ajs25]: But this gets highest priority at line 905 above

- Employ data rescue activities to preserve the historical observation record in developing countries, and make long-term datasets available for activities including reanalysis, research, adaptation, monitoring and other climate services.
- Encourage Regional Associations in concert with CBS to define field experiments over data sparse areas, for a limited time, to evaluate how additional data would contribute to improve performance at the regional and global scale, following the example of the African Multidisciplinary Monsoon Analysis (AMMA[24]) field experiment.
- Examine the extent to which automated stations could become a viable, cost-effective alternative to manned stations for the surface network in the future, and investigate improved configurations of automated and manual stations.
- Examine how, in data-sparse areas of the world, it may be more cost-effective to make full use of AMDAR ascent/descent data at major airports, whilst noting that the radiosonde network still plays an important role in manual forecasting.

Comment [ajs26]: Repetitive

- When changes are made to the climate observing systems, follow the GCOS Climate Monitoring Principles (GCMP) and proper change-management practices, with close collaboration between observations managers and climate scientists.[25] Refer telecommunication problems to CBS, as a priority. Note that for nowcasting and risk mitigation in vulnerable areas, the availability of a robust telecommunication infrastructure is an issue (robust against extreme weather conditions).

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- **Action C11**
  - **Action**: Establish capacity building strategies in developing countries. This may include establishing training programmes through engagement within the targeted country, e.g., data management, observing practices and seasonal prediction. Use the regional climate centre concept to provide access to specialists who could conduct training and maintenance of more complex systems including AWS.
  - **Who**: NMSs / NMHSs with RAs, CBS, Commission on Climatology (CCl) in collaboration with international programmes. Initiation and supervision to be led by RAs.
  - **Time-frame**: Continuous. Timetable to be decided by each RA.
  - **Performance indicator**: capacity building development in developing countries.
  -

Comment [j27]: This sounds fine but what's new?! should we try to be more specific. in order to be more useful?

Comment [j28]: Is seasonal prediction in scope for EGOS-IP?

Comment [j29]: Other Commissions - agreed - but why CCl in particular?

5. Surface-based observing system

5.1. Introduction

The surface-based component of the GOS was developed originally to meet the requirements of operational meteorology without consideration of the new and emerging applications now covered by WMO Programmes. The issue of complementarity with the space-based component of the GOS started to be taken into account in the decade 1970-80.

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[24] See http://amma-international.org/

[25] See WMO-TD No 1378 on: http://www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMPNo62.pdf

For observing the upper atmosphere, the upper-air synoptic stations (consisting of radiosondes, radio-wind and PILOT[26] balloons stations) were originally the unique surface-based observing system, until they were complemented by aircraft meteorological measurements and later by remotely-sensed observing systems (profilers and weather radars). The radiosonde station density has always been inadequate with respect to the meteorological requirements over the oceans and desert areas.

For observing the atmosphere near the surface, the surface synoptic stations' network is denser than for the upper-air. Over land it consists mainly of the manned and automatic surface stations. Over sea, it consists mainly of ships of the Voluntary Observing Ships scheme (VOS), fixed and mobile buoys. Many stations which originally served a single purpose (e.g., serving only synoptic or climatological, agrometeorological or aviation purposes) have evolved into multi-purpose stations serving multiple programmes and users.

Global synoptic and climatological networks are composed of the Regional Basic Synoptic and Regional Basic Climatological Networks (RBSN/RBCN). RBSN/RBCN should satisfy minimum regional requirements in order to permit WMO Members to fulfil their responsibilities within the World Weather Watch and for monitoring of climate.

Observing practices are included in the Manual of the Global Observing System (WMO-No. 544) and the Guide on the Global Observing System (WMO-No. 488). Individual Actions in this Implementation Plan may result in changes of best practices and in a need to update the above WMO regulatory material. Evolving needs in areas of integration, automation, interoperability, data compatibility, consistency and homogeneity will have to be recognized in the WMO regulatory material. This will be addressed within the implementation of WIGOS and a development of the WIGOS Manual and Guide.

Observing the deep ocean remains a challenge: it cannot be done from space, and very few in-situ systems are available (Expendable bathy-thermograph - XBT - instruments from ships, profiling floats). The observation of the ocean surface is less challenging as the satellites can contribute to a large extent, and the observation systems used for meteorology (ships, buoys) can also carry instruments for measuring surface variables like SST.

For observing the land surface, some measurements may be made by surface synoptic stations (such as soil temperature at different levels, state of the ground snow depth and soil moisture). There is also a large variety of stations and networks developed independently for various applications, such as hydrology, urban meteorology, agriculture, monitoring of air pollution, electrical power production. They provide a large variety of variables which are potentially useful for several disciplines and which should be integrated.

Some observations of the land-based cryosphere are part of operational networks; others are part of research programmes and are not acquired in a consistent manner. For example, snow depth is regularly measured at many land stations; lake ice cover and glacier mass balance are not. Some critical snow and ice properties, such as snow water equivalent (SWE) and permafrost properties, are difficult to measure from space, though new techniques and satellite sensors are promising. The GCW will evaluate the surface and space-based cryosphere observing systems and will provide recommendations for reducing the gap between current capabilities and user needs.

Comment [j30]: Some good points, but do they belong here? - they also address space-based systems

Instruments need to be sufficiently robust to sample extremes in keeping with the climatology of the region in which deployed. For supporting improved forecasts and climate science, it is essential to withstand high winds, lightning strikes, and to adequately measure extremes in temperature and precipitation.

[26] Upper-wind report from a fixed land station

By 2025, there will be an increased tendency towards the integration of the surface-based observing systems of the three climate components: atmosphere, ocean, terrestrial system. This tendency to integration is natural in the context of the climate monitoring and prediction which require observations from the three components. “Integration” also means that there will be more multi-purpose instruments, stations and networks, and more progress on data interoperability, data exchange and data processing.

Data volumes for some observing systems, such as radiosondes or the surface synoptic stations, will stay relatively small. By contrast, for remote-sensing observing systems such as radar, the observed data volume is expected to grow fast (with similarities to satellite data), and the exchanged data volumes are expected to grow even faster.

In the following section (5.2), the generic issues concerning the surface-based global observing systems are put together, with the corresponding recommendations which are appropriate for its implementation in the period 2012-2025. Section 5.3 describes the recommended Actions for the different observing systems which should be used operationally by 2025. Section 5.4 describes some possible research / development activities which should be carried out by 2025, aiming at improving the observing systems.

5.2. Generic issues: traceability, instrument calibration, data exchange

To guarantee data quality, especially for climate applications, instrument measurements should be traceable to the International System of Units (SI) that should be done through an unbroken chain of comparisons, quality assessments and calibrations of instruments and respective working international standards.

Action G1

Action: Ensure traceability of meteorological measurements to SI, at least within the Regional Basic Synoptic and Climatological Networks (RBSN/RBCN).
Who: NMSs / NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead and supervise.
Time-frame: Continuous
Performance indicator: Number of stations that make measurements traceable to SI.

The increase of data volumes for some specific observing systems, such as radars and wind profilers, has to be accompanied by actions ensuring capability of WIS to cope with the corresponding increase of data exchange. This increase will be partly due to more frequent observations, e.g., through the automation, or to exchange of existing observations that were not exchanged internationally.

OSEs performed with NWP models have shown that global forecasts can be improved significantly by assimilating hourly data, even if the data are available only on a small portion of the globe, such as hourly atmospheric pressure observations from synoptic stations, radar data, data from Global Navigation Satellite Systems (GNSS) receiving stations. Similarly, other applications, including climate and aviation, rely increasingly on sub-hourly data. Open and unrestricted access to all available data and their exchange would be needed to improve scope and quality of services provided by NMSs / NMHSs to their users.

Action G2

Action: Ensure, as far as possible, a global exchange of hourly data which are used in global applications, thinned if necessary to balance user requirements against technical limitations.
Who: NMSs/NMHSs, Regional Associations, in coordination with CBS and international programmes and agencies. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.

Performance indicator: the standard monitoring indicators used in global NWP (see footnote 18 in section 3.6).

Action G3

Action: Promote a global exchange of sub-hourly data in support of relevant application areas.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: A number of sub-hourly data types exchanged through WIS.

Climate modelling and seasonal forecasts require also an exchange of data between the different centres monitoring the atmosphere, the ocean and the terrestrial sub-system. Although the real-time constraints are less severe than for NWP, it is important to integrate these different observation systems, with common pre-processing and exchange rules, following the WIS and WIGOS standards. Such an action would improve considerably the benefits to the users without creating new observing systems. As the different users have different operational constraints and different requirements in data resolutions, this may imply, for some observing systems producing high data volumes, to organize the processing with different data levels (as done already for many satellite missions).

Action G4

Action: Ensure exchange of observations from atmosphere, ocean, terrestrial observing system, according to the WIGOS standards. If needed, organize different levels of pre-processed observations in order to satisfy different user requirements.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations. CBS to lead the action.
Time-frame: Continuous. Timetable to be decided for each observing system.
Performance indicator: Statistics on the data made available to each application.

Mainly for the climate monitoring, but also for other applications, it is important:

- to maintain stations with long historically-uninterrupted observation records;
- to perform a regular calibration of instruments;
- to test and intercompare different observing instrument/systems (e.g., radiosonde systems and remote-sensing systems providing different types of vertical profiles with a view of establishing the interoperability of their data);
- to collect and archive sufficient metadata to enable homogeneity assessments to be made and data provenance and fitness for purpose to be assessed;
- for all countries to maintain their GCOS (GSN, GUAN, and RBCN) stations and for these to provide observations on a continuing basis as long as possible.

For more details, see the Quality Management Framework (footnote 15), section dedicated to instruments and observation methods.

5.3. Issues specific to each observing system component

5.3.1. Upper-air observing systems over land

5.3.1.1. Upper-air synoptic and reference stations

5.3.1.1.1. Radiosonde data coverage: optimization

NWP impact studies have consistently shown the importance of isolated radiosonde data (see reference to WMO Workshop Proceedings, footnote 20 in section 4), and a network of upper air measurements of sufficient coverage is required for climate monitoring. Inadequacies include some

Comment [j31]: Here and elsewhere: consider including reference to WMO Workshop 2012.

large continental regions that are not monitored by any radiosonde site. It is essential to reduce these big gaps in the radiosonde data coverage, or at least, to prevent these gaps from expanding.

It is essential to maintain operational radiosonde stations in the least observed areas of Regions I, II and III, keeping in mind that the optimization of the radiosonde coverage cannot be done independently of other observing systems, especially of aircraft observations.

Action G5

Action: Expand radiosonde stations, or at least re-activate silent radiosonde stations, in the data sparse areas of Regions I, II and III which have the poorest data coverage. Make all possible effort to avoid closing of existing stations in these data sparse areas, where even a very small number of radiosonde stations can provide an essential benefit to all the users.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations. CBS to lead the action together with the RAs.
Time-frame: Continuous
Performance indicator: The standard monitoring indicators used in NWP (see footnote 18 in section 3.6).

5.3.1.1.2. GUAN and GRUAN stations

A selection of upper-air stations from RBSN/RBCN which are significant for both synoptic and climatological purposes form a baseline network called GCOS Upper-Air Network (GUAN). GUAN stations (currently 173) are also used to validate satellite data. GCOS is in the process of coordinating implementation of a upper-air reference network for upper-air climate observations (GRUAN) that is expected to provide long-term, highly accurate measurements of atmospheric profiles, complemented by ground-based state of the art instrumentation in order to fully characterize the properties of the atmospheric column and their changes. GRUAN is envisaged as a network of 30-40 high-quality, long-term, upper-air observing stations, building on existing observational networks, such as GUAN, the Global Atmospheric Watch (GAW), RBSN and GSN, and providing complete metadata for traceability of measurements. Because there is no other upper-air observing system able to provide a reference at fixed points (satellite and aircraft data are obtained at different positions from one day to another), it is very important to maintain the GUAN and develop the GRUAN (see also section 5.4.3).

Action G6

Action: Improve quality, availability and sustainability of GUAN, ensuring the health and maintenance of the existing network.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations. GCOS to lead the action.
Time-frame: Continuous.
Performance indicator: The standard monitoring indicators used in NWP.

Action G7

Action: Continue implementation of GRUAN through support and development of the initial 15 stations and eventual completion of the full 30-40 station network.
Who: GCOS to lead the action in coordination with NMSs/NMHSs, WMO own and co-sponsored programmes, Technical Commissions, RAs, and other relevant organizations.
Time-frame: Continuous.
Performance indicator: The standard monitoring indicators used in NWP and the indicators defined in the GRUAN Observation Requirements.

5.3.1.1.3. Improved dissemination

Data from some radiosonde stations are never internationally exchanged in real-time over the GTS, although they may be exchanged and archived locally and made available for climatological purposes. In some cases data exchange over the GTS has several hours delay, which reduces considerably there use for operational purposes. In many cases telecommunication hardware problems or software coding problems are responsible for unavailability of data.

Action G8

Action: Identify radiosonde stations that make regular measurements (including radiosondes operated during campaigns only), but for which data are not transmitted in real-time. Take actions to make data available.
Who: NMSs / NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead the action.
Time-frame: Continuous.
Performance indicator: A number of the above radiosonde stations providing data to GTS, plus standard monitoring indicators on radiosonde data availability and timeliness.

5.3.1.1.4. Associated metadata

Many radiosonde observations are thinned (reduction of vertical resolution of the measured profiles) before they are internationally exchanged and assimilated in real-time. As a consequence, NWP and other applications do not have access to radiosonde data at high-vertical resolution, from which they could now derive significant benefits. Also the user has no access to the exact position and time of each datum. The development of BUFR code for radiosonde data has been driven primarily by the need to address these problems and should help to solve most of the dissemination problems.

Action G9

Action: Ensure a timely distribution of radiosonde measurements at high vertical resolution, together with position and time information for each datum.
Who: NMSs/NMHSs, in coordination with WMO own and co-sponsored programmes, TCs, RAs, and other relevant organizations. CBS and RAs to lead the action.
Time-frame: Continuous.
Performance indicator: Number of radiosonde sites providing the high resolution profiles.

This Action consists of two sub-actions: (I) To code the radiosonde observation in high resolution BUFR (rather than low-resolution BUFR or TEMP[27]); (ii) To transmit the position and time of each datum.

5.3.1.1.5. Adaptive radiosonde network

Although the radiosonde network is operated from fixed points, it has been shown that increased efficiency may be reached by varying the observation time or the launch frequency at some radiosonde sites, as confirmed by tests done by the Network of European Meteorological Services (EUMETNET) Composite Observing System (EUCOS[28]). Benefits can be drawn in the coming years by making the existing radiosonde network more adaptive or at least more optimal in time-space coverage.

Action G10

Action: Continue the studies and tests on the usefulness of observations obtained by increasing the frequency of radiosonde launches at some observation sites, in relation with the meteorological situation in the area.

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27 FM-35 TEMP GTS format : Upper-level pressure, temperature, humidity and wind report from a fixed land station
28 See http://www.eucos.net/cln_016/EN/Home/eucos__node.html?__nnn=true

Who: NMSs / NMHSs, research institutions and other organizations operating radiosonde networks or organizing field-experiments, with the NWP centres. CBS and CAS/THORPEX to lead the action.
Time-frame: Continuous, with a time-table depending on regional campaigns.
Performance indicators: A number of radiosonde sites able to become "adaptive" together with the number of observations made (standard monitoring).

Comment [j32]: Since THORPEX is ending soon, should it be named to lead an Action? Same issue with some other Actions.

Action G11

Action:
Optimize the radiosonde network in order to make the upper-air conventional observation coverage more uniform in space and time. This action should tune at least the following features: (I) The radiosonde observation time (e.g.: can it be switched from 00 to 18 or 06UTC?); (ii) The distance from the radiosonde sites to the airports (where AMDAR data can be easily obtained); (iii) The radiosonde time-series required by climate applications at fixed sites and regular times.
Who: NMSs / NMHSs, in coordination with WMO's own and co-sponsored programmes, Technical Commissions, RAs and other relevant organizations. CBS and RAs to lead the action.
Time-scale: Continuous.
Performance indicators: Standard monitoring indicators

Comment [j33]: This Action was queried by Li Bai, CMA. Drafting group / ET-EGOS to discuss.

Comment [ajs34]: Are you confident these are the bodies to properly respect the value of radiosonde data for climate?

Action G12

Action: Reconsider radiosonde network designs, taking into account other available sources of data, such as AMDAR and wind profilers.
WHO: CBS through NWP impact studies and network design studies, in coordination with NMSs / NMHSs, WMO own and co-sponsored programmes, other Technical Commissions, RAs and other relevant organizations. CBS and RAs to lead the action.
Time-scale: 2015 for a first redesign.
Performance indicators: Design developed and implemented.

5.3.1.1.6. Observation of the stratosphere

Only 10 to 20% of the operational radiosonde stations reach generally the 10hPa (about 30km) height. Except for some stations from the GRUAN network, whose role is also to serve as reference observations in the lower stratosphere, it is not cost-effective to develop radiosonde technologies for measurements in the stratosphere.

Comment [ajs35]: What does this mean. What price climate? We have had radiosonde technologies for measuring the lower stratosphere for decades. And I suspect that in the good old days a higher percentage of sondes reached 10hPa - at least this should be checked for the data used in reanalysis.

NWP impact studies have shown that the radiosonde data above 100hPa do have a positive impact on forecasts through NWP data assimilation, including on the forecast of tropospheric fields. However these studies were conducted in a context where neither current satellite sounders nor the GNSS radio-occultation data were assimilated. The question of the usefulness of radiosonde data above 100 hPa should then be reassessed, while recognizing the requirement for continuity of data above 100hPa for climate monitoring.

Comment [ajs36]: It's more than this. The radiosondes anchor the radiance data bias correction for NWP as well as reanalysis. And at present the commitment to radio occultation is not strong enough for us to rely on there being an adequate coverage.

Moreover, radiosonde wind data are vital for depicting the QBO in the tropical stratosphere.

And the tropopause in the deep tropics is located above 100hPa.

If you are to do an OSSE to look at the impact on forecasts, you should do an OSSE for climate.

I really dislike this one.

Action G13

Action: Perform NWP impact studies to evaluate the impact of radiosonde data above 100hPa on global NWP, in the context of current observing systems (2012).
Who: NWP centres, coordinated by CBS/ET-EGOS and CAS/THORPEX.
Time-scale: Before 2013 (end of THORPEX).
Performance indicators: A number of independent studies carried out.

Observing System Simulation Experiments (OSSEs) are needed to evaluate the impact of a "perfect" atmosphere above 100hPa on the tropospheric forecasts. The idea is to give a quantitative estimate of the maximum benefit which could be obtained in NWP through improved observation of the stratosphere. OSSEs made with a variable number of radiosonde sites (providing data above 100hPa) could be compared to this upper limit.

Action G14

Action: Perform OSSEs to evaluate the impact of improved information above 100hPa on the tropospheric forecasts.
Who: NWP centres, coordinated by CBS/ET-EGOS and CAS/THORPEX
Time-scale: Before 2013 (end of THORPEX)
Performance indicators: A number of independent experiments of this kind carried out.

5.3.1.2. Remote-sensing upper-air profiling stations

A variety of remote sensing techniques are emerging for measuring some parts of the atmospheric profile of wind, temperature and humidity. Radar wind profilers are used operationally in many regions. Vertical profiles of wind are also derived from Doppler weather radars in many regions, while Doppler lidar and microwave radiometers are being introduced in some regions. Some devices can be used to measure aerosol, cloud properties and trace species in the atmosphere. Ceilometer data are used to monitor the height of the planetary boundary layer and volcanic ash. GALION (Global Atmospheric Lidar Observing Network) is a project aimed at the development of a global network of lidar stations for the observation of atmospheric aerosols. See: http://alg.umbc.edu/galion/

Compared to the radiosonde measurements, the remotely sensed observations are providing data with much higher frequency. However currently they have a strong limitation in terms of data coverage. Only very few systems are technically able to measure atmospheric profiles from the boundary layer to the stratosphere. Most profilers measure only one variable in one part of the atmosphere, for example, the wind in the boundary layer. In future, the large variety of profiler instruments should be developed and used by an increasing number of applications. This is important from the point of view of complementing the radiosonde and aircraft profiles in the lower and upper troposphere. It would be an advantage to develop regionally an homogeneous network of remote-sensing profiling stations with a few sites integrating a large range of instruments and observing simultaneously (e.g.) wind, temperature and humidity.

Action G15

Action: Develop homogeneous networks of remote-sensing profiling stations on the regional scale in order to complement the radiosonde and aircraft observing systems, mainly on the basis of regional, national and local user requirements (although part of the measured data will be used globally).
Who: Organizations operating profiling stations in routine or research mode, in coordination with NMSs / MNHSs, RAs, Technical Commissions (mainly CAS, CBS and CIMO) and other regional institutions (e.g.: EUMETNET in Europe). CBS to lead the action with CIMO, CAS and RAs.
Time-scale: Continuous. Detailed timetables to be set up by RAs at the regional level.
Performance indicators: A number of profiling stations providing quality-assessed data in real-time to WIS/GTS.

Comment [j37]: Li Bai suggested OSSEs to support this Action. Suggestion passed to Rapportuer for OSEs/OSSEs. Drafting group / ET-EGOS to consider

Global data assimilation schemes are able to assimilate observations which are produced every hour, or even more frequently, and they are able to draw benefits from such frequent observations even if they are produced by few limited profiling stations round the globe. It is useful to exchange globally data profiles produced on a hourly basis (or at least a subset). Appropriate data representation in BUFR should be available for this purpose.

Action G16

Action: Ensure, as far as possible, the required processing and the exchange of profiler data for local, regional and global use. When profiler data can be produced more frequently than 1 hour, a dataset containing only hourly observations can be exchanged globally following the WIS principles.

Who: Organizations operating profiling stations in routine or research mode, in coordination with NMSs/MNHSs, RAs, Technical Commissions (mainly CAS, CBS and CIMO) and other regional institutions (e.g.: EUMETNET in Europe). CBS to lead the action together with the RAs.
Time-scale: Continuous. Detailed timetables to be set up by RAs at the regional level.
Performance indicators: A number of profiling stations exchanged globally.

5.3.1.3. Aircraft meteorological stations

Comment [ajs38]: I would not use the word stations here. Aircraft make measurements when in flight, not when they are stationary.

In the northern hemisphere, meteorological data derived from aircraft platforms, especially the automatic data produced by the AMDAR system, are an excellent complement to the data derived from the radiosonde network. This system produces vertical profile data in the vicinity of airports and single-level data when aircraft are flying at cruise levels. It has been shown through NWP impact studies that their impact on numerical forecasts has a magnitude similar to the impact of the radiosonde network. In the southern hemisphere and in the tropics the aircraft data coverage is very poor although there is some potential for developing it, preferably in a way that is complementary to existing AMDAR and radiosonde networks.

Extending aircraft observations data coverage is important and can be achieved through the extension of the programme to new airlines and aircraft operating in data-sparse areas. The programme coverage can also be improved greatly through an optimization process. This can be achieved through two general activities. Firstly, existing programmes can be extended so that internationally-operating aircraft are activated for reporting outside the national areas or regions that tend to be restricted by national programme constraints. Secondly, one can enhance the capabilities of programmes to control data output through the wider development and implementation of automated data optimization systems. Such systems, whilst allowing the efficient growth of the programme outside and across international boundaries with appropriate agreements in place, will also offer the potential to utilize the AMDAR system as an adaptive observing network (capability to change the reporting regime to serve the changing purposes of programme areas).

Action G17

Action: Improve AMDAR coverage over areas that currently have poor coverage, especially within Regions I and III, focussing on the provision of data at airports in the tropics and southern hemisphere where vertical profiles are most needed to complement current radiosonde data coverage and its likely evolution.
Who: NMSs, NMHSs in collaboration with commercial and other airlines, Regional Associations. CBS and AMDAR Panel to lead the action.
Time-scale: Continuous
Performance indicators: Number of airports where AMDAR measurements are taken. Amount of vertical profiles and AMDAR data in general, measured by the usual indicators of current AMDAR programmes.

Action G18

Action: Extend the AMDAR Programme so as to equip and activate more internationally-operating fleets and aircraft (i.e. fleets and aircraft flying to and between international airports outside the country of origin) and extend the use of data optimization systems in support of improved upper air observations coverage and efficiency, and also the adaptive functionality of the system.
Who: NMSs, NMHSs in collaboration with commercial and other airlines, Regional Associations, CBS and AMDAR Panel. CBS and AMDAR Panel to lead the action.
Time-scale: Continuous
Performance indicators: The number of airports where AMDAR measurements are taken and number of vertical profiles per day at each airport. The number of international airlines and aircraft equipped to provide AMDAR observations. The adaptability of the AMDAR programme.

Action G19

Action: Given the nature of the aircraft observing system as an increasingly critical and basic component of the Global Observing System, seek to establish agreements with airlines and the aviation industry to ensure that the system, infrastructure, data and communications protocols are supported and standardized within relevant aviation industry frameworks so as to ensure continuity and reliability of the system.
Who: NMSs, NMHSs in collaboration with national and other airlines and aviation industry, Regional Associations, CBS and AMDAR Panel. CBS and AMDAR Panel to lead the action.
Time-scale: Continuous
Performance indicators: Agreements made with aviation industry partners and organizations.

Humidity sensors are now used operationally on an increasing number of aircraft both in the USA and Europe, and it is critical and strategic to continue this development in order to converge to systems which measure humidity as well as air pressure (pressure altitude), temperature and wind as do radiosondes. Such an extension will provide an increased opportunity to restructure the upper air observing systems for efficiency and improvement in coverage.

Action G20

Action: Continue the development and operational implementation of humidity sensors as an integrated component of the AMDAR system to ensure that humidity data is, processed and transmitted in the same way as wind and temperature.
Who: NMSs, NMHSs in collaboration with commercial and other airlines and WMO commissions (CBS, CIMO) and AMDAR Panel. CBS and AMDAR Panel to lead the action.
Time-scale: Continuous.
Performance indicators: A number of aircraft providing humidity data in real-time.

The lower cost of aircraft observations in comparison to the radiosonde information as well as the reduced reliance on ground-based systems and infrastructure make it an ideal candidate system for rapid and reliable expansion of upper air observations for developing countries in support of local, regional and global data users. Such an expansion should be undertaken in parallel with the necessary development action to facilitate the provision and utilization of data.

Observations of turbulence and icing are also made on some aircraft and it is desirable to expand this capability of the AMDAR system with these parameters in support of aviation operations and safety as well as other meteorological applications.

Action G21

Action: Enhance and extend the capability to report observations of atmospheric turbulence and icing variables as an integrated component of the AMDAR system and in line with the requirements of the relevant programme areas and data users.
Who: NMSs, NMHSs in collaboration with airlines and WMO TC (CBS, CIMO) and AMDAR Panel, RAs. CBS and AMDAR Panel to lead the action.
Time-scale: Continuous.
Performance indicators: A number of aircraft providing atmospheric turbulence and icing data in real-time.

AMDAR systems for smaller General Aviation aircraft, which usually involve the deployment of a sensor and communications package, have been tested in some areas and on a limited number of aircraft. However, due to the application of a different data policy, data from these systems are not currently used in full operational mode and not made available to data users on a global basis in real time. These aircraft tend to fly and generate level data in the middle troposphere whilst operating over shorter regional flight legs. This type of observation would be very useful for regional and local purposes and could also contribute to optimizing global data coverage. Priority should be placed on equipping aircraft operating on, to and out of isolated islands and remote sites where radiosonde observations are not available, e.g. deserts, islands and the Arctic.

Action G22

Action: Develop and implement operationally AMDAR systems which are adapted to small aircrafts operating at the regional scale and flying at low altitude in the troposphere.
Who: Airlines operating small aircraft, NMSs, NMHSs in collaboration with Regional Associations, CBS and AMDAR panel. CBS and AMDAR Panel to lead the action.
Time-scale: Continuous
Performance indicators: number of small aircrafts providing AMDAR observations operationally in real-time.

Atmospheric composition measurements for several species, aerosols and volcanic ash are measured on some aircraft, but more in research than in operational mode. The actions related to atmospheric chemistry are documented in section 5.4.4.

Comment [ajs39]: Now, perhaps, but this is about the vision to 2025. This should be made a bit more positive, or deleted here and left to section 5.4.4.

5.3.1.4. Global Atmosphere Watch stations

Surface-based observations of atmospheric composition, complemented by aircraft measurements, will contribute to an integrated three-dimensional atmospheric chemistry observation network, together with a space-based component. Networks exist which are making regular measurements of ozone (profile and total) and of several other chemical variables. See GCOS-IP (especially its section about atmospheric chemistry) and the strategic plan 2008-2015 of the WMO GAW[29]. The actions suggested in the GCOS-IP for maintaining and enhancing the networks and for increasing the coverage in the tropics and southern hemisphere should be supported also for non climate applications. In addition, when the atmospheric composition observations are frequent enough, they should be processed and disseminated in real-time, in order to be used in several applications whose requirements are documented in the RRR.

Action G23

Action: Ensure, as far as possible, a real-time or at least near-real-time exchange of data from the operational GAW and GCOS stations. Follow the WIGOS and WIS standards for data international exchange.
Who: NMSs / NMHSs and respective organizations and research agencies conducting atmospheric composition observations, in coordination with TCs (especially with CAS and CBS) and Regional Associations. CAS and CBS to lead the action with RAs.
Time-scale: Continuous. Timetable to be defined for each RA.
Performance indicators: A number of atmospheric composition stations made available in real-time.

5.3.1.5. GNSS receiver stations

In a similar way to the atmospheric profilers, networks of GNSS ground-based receiver stations have been operational in few regions round the world. The main application of these networks is generally not meteorological. Although they are very heterogeneous in quality and observing practices, the meteorological information has been extracted and collected in real-time from some stations. Starting in 2006, the meteorological information has been assimilated in operational NWP (both global and regional) either in the form of an Integrated Water Vapour (IWV = total water vapour integrated on the vertical), or in the form of a Zenith Total Delay (ZTD). The ZTD contains both the “wet delay” (due to the water vapour) and the “dry delay” directly related to the air density (air density directly related to surface pressure). The positive impact of GNSS ground-based meteorological observations on numerical forecasts has been shown (on the water vapour, precipitation and atmospheric pressure fields). See footnote 20 in section 4 to access to a synthesis of OSEs.

[29] ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw172-26sept07.pdf

The ground receiver stations in most countries are owned and operated by agencies other than the NMHS. Hence the access to data, the processing to produce meteorological data, and permission to use and redistribute the data are all dependent on collaboration by the NMHS (individually or in multilateral groupings) with the owners/operators. In many cases it is not permitted for the NMHS (individually or in multilateral groupings) to exchange the data with other Members of WMO.

Concerning this observing system which is relatively new in meteorology, one important action is to exploit more the meteorological content of the existing GNSS receiver stations (in the form of IWV or ZTD). This action does not require deployment of new infrastructure. In addition, it would be very beneficial to improve the observation of upper-air humidity with denser receiver networks, taking into account all the other instruments that observe the upper-air humidity, and looking especially at areas for which the climatology is subject to rapid variations (in space and time) of the atmospheric water vapour content.

Action G24

Action: Exploit more the existing GNSS receiver stations by establishing collaborative arrangements with station owners / operators for access to data, processing of data to derive meteorological information (ZTD, IWV) and, where possible, permission to exchange the data with other Members of WMO.
Who: NMSs / NMHSs (individually or in multilateral groupings) will lead the Action and will need to collaborate with station owners/operators, with RAs (to determine exchange requirements), and with WMO TCs (for relevant guidance).
Time-scale: Continuous.
Performance indicators: Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring (see footnote 18 in section 3.6).

Action G25

Action: Organize the global exchange of data from a subset of GNSS receiver stations, aiming at satisfying a frequency requirement of about one hour (for meeting requirements in global applications).
Who: Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs / NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g., EUMETNET). CBS to lead the action with RAs.
Time-scale: Continuous.
Performance indicators: A number of GNSS receiver stations whose data are exchanged globally in real-time.

Action G26

Action: Optimize the upper-air water vapour observation over land, considering the collaborative establishment of additional GNSS receiver stations, and also the other humidity observing systems.
Who: Organizations and research agencies operating GNSS receiver stations, in coordination with NMSs / NMHSs, with RAs, TCs (especially CAS and CBS) and other international organizations (e.g., EUMETNET). NMSs / NMHs to lead the action with RAs.
Time-scale: Continuous.
Performance indicators: Number of GNSS receiver stations making available their data in real-time; number of stations which can be used in NWP according to the usual monitoring (see footnote 18 in section 3.6).

5.3.2. Surface observing systems over land

5.3.2.1. Surface synoptic and climatological stations

Comment [ajs40]: No mention of METARs. Why? ECMWF assimilates this form of data, which cover parts of the world where there is only sparse data otherwise.

Land-surface observations come from a wide variety of in-situ networks, and they serve the requirements of many application areas. Surface synoptic and climatological stations provide measurements at the interface between the atmosphere and the land surface, and also other qualitative or quantitative observations related to atmospheric or environmental phenomena, such as visibility, present weather, cloud height, cloud type, thunderstorms, lightning, type of precipitation, which are increasingly important for emerging environmental societal applications. For NWP the important variables are surface pressure, surface wind, air temperature and humidity, precipitation and the state of the ground, including snow depth and soil moisture). Most of these variables can be assimilated in NWP models with a hourly frequency, therefore, the global exchange of these data should be adapted accordingly. There are also many variables that serve the full needs of the climate services community, and there is a growing requirement for high frequency measurements and near real-time transmission and data collection. These include but are not limited to ECVs listed in the GCOS-IP. In addition climate reference stations are being established to provide the highest quality observations for climate monitoring while also supporting forecasting through hourly data transmission.

Action G27

> **Action**: Ensure, as far as possible, global exchange of variables measured by surface synoptic and climatological stations with at least one hour frequency and in real-time.
> **Who**: NMSs/NMHS, RAs and TCs, coordinated by CBS.
> **Time-scale**: Continuous.
> **Performance indicators**: A percentage of observations exchanged globally with a one hour frequency (with respect to the number of stations observing hourly).

An increasing number of variables are measured automatically with required quality. The trend to automation is encouraged, as it could improve the data compatibility and the data coverage, especially from remote locations, and the frequency and availability of data in real-time. Currently, many observations made routinely are not distributed in real-time, although requirements are documented in the RRR, and automation does provide new opportunities for disseminating variables that were in the past collected but not shared in real time.

In addressing the increasing trend in automation of observations, CBS and CIMO have developed guidelines and procedures for the transition from manual to Automatic Weather Stations (land and marine). Once published, they will be available on the WMO web site[30].

Action G28

> **Action**: Improve data compatibility, availability (also with higher frequency) and data coverage of surface synoptic and climatological observations through automation and exchange of data in real-time, as far as possible from all operational stations, without degrading the quality.
> **Who**: NMSs/NMHS, RAs and TCs, coordinated by CBS.
> **Time-scale**: Continuous.
> **Performance indicators**: A percentage of stations distributing quality-assessed observations in real-time over WIS/GTS (with respect to the number of stations producing observations).

Several observations are made and transmitted routinely, but they are exchanged in formats which are not adequate enough to contain required metadata needed for appropriate use in data assimilation and in other tools. This is particularly true for the atmospheric pressure which is usually measured with a very good accuracy, but cannot be used without accurate information of the barometer altitude. Another example of needed metadata information is the altitude where the wind measurement is taken. Other variables including temperature and precipitation and other elements for climate services are also transmitted without adequate metadata.

Actions aiming at improving the quality, the consistency and the availability of the surface synoptic and climatological observations are particularly important for climate applications and will contribute building long-term series of observations and re-analyses. All the actions of the GCOS-

[30] http://www.wmo.int/pages/prog/www/IMOP/publications-IOM-series.html

IP (section dealing with the surface observations of the atmospheric domain) must be supported also for non climate applications.

Action G29

Action: Ensure variables measured by surface synoptic and climatological stations are exchanged together with required metadata according to WIGOS and WIS standards. Special attention should be given to the barometer altitude uncertainty.
Who: NMSs /NMHS, RAs and TCs, coordinated by CBS.
Time-scale: Continuous.
Performance indicators: Usual monitoring indicators (see footnote 18 in section 3.6).

Action G30

Action: Improve design of the Regional Basic Synoptic Network (RBSN) and the Regional Basic Climatological Network (RBCN).
Who: CBS leading the action through the appropriate NWP impact studies and network design studies, in coordination with NMSs/NMHSs, WMO-owned and co-sponsored programmes, other TCs, RAs and other relevant organizations.
Time-scale: 2015.
Performance indicators: Design developed and implemented.

5.3.2.2. Global Atmosphere Watch stations

Surface observations of atmospheric composition will contribute to an integrated three-dimensional atmospheric chemistry observation network, together with upper-air measurement stations (ground-based, aircrafts, balloons) and with a space-based component. Surface observations of CO_2 and CH_4 are very important for identifying sources and sinks in atmospheric chemistry and for understanding the radiative influences on climate (see document referenced in footnote 29 in section 5.3.1.4, and also the GCOS-IP). The data coverage in CO_2 and CH_4 is clearly insufficient for global observing requirements and for surface observations of atmospheric composition. A priority is to implement the actions explained in the section of the GCOS-IP dealing with atmospheric composition.

By 2025, models used for NWP and climate modelling will be increasingly coupled to ACM and to models used to monitor and forecast air quality. In support of this, it will be important progressively to integrate the corresponding observing networks, so that atmospheric composition observations that are made regularly are made available in real-time.

Action G31

Action: Implement as soon as possible a real-time exchange of the atmospheric composition observations which are made every day in surface stations. Follow the WIGOS and WIS practices for implementing this dissemination, and the standard quality assessment practices.
Who: Organizations and research agencies operating atmospheric composition observations, in coordination with NMSs / NMHSs, the RAs and TCs. CAS and CBS to lead the action with RAs.
Time-scale: Continuous. Timetable to be established for each RA.
Performance indicators: A number of surface atmospheric composition stations making quality-assessed data available in real-time.

5.3.2.3. Global Cryosphere Watch stations

The recently established Global Cryosphere Watch (GCW) programme will initiate a comprehensive cryosphere observing network called "CryoNet", a network of reference sites or "super-sites" in cold climate regions, operating a sustained, standardized programme for observing and monitoring as many cryospheric variables as possible. Initially, it will build on existing cryosphere observing programmes or add standardized cryospheric observations to existing facilities to create super-site environmental observatories. The combination of snow/ice and meteorological measurements will allow for robust analyses of energy and mass fluxes. As encouraged by GCOS, GCW will facilitate the establishment of high-latitude super-sites with co-located measurements of key variables, especially permafrost and snow cover, thus enhancing GCOS/GTOS Networks for Permafrost (GTN-P), Glaciers (-G) and Hydrology (-H). GAW stations and WCRP/Coordinated Energy and Water Cycle Observations Project (CEOP) reference sites in cold climates are potential candidates.

Action G32

Action: Implement as soon as possible a comprehensive cryosphere observing network of reference sites “CryoNet”.
Who: Organizations and research agencies operating stations for cryospheric observations, in coordination with NMSs / NMHSs, the RAs and TCs (CAS, CBS). CAS and CBS to lead the action.
Time-scale: 2014.
Performance indicators: A number of reference stations taking part in CryoNet.

Action G33

Action: Provide, as far as possible, a real-time exchange of the cryospheric data from CryoNet. Follow the WIGOS and WIS practices for implementing this dissemination, and the standard quality assessment practices.
Who: Organizations and research agencies operating stations for cryospheric observations, in coordination with NMSs / NMHSs, the RAs and TCs (CAS, CBS).
Time-scale: 2014.
Performance indicators: A number of CryoNet stations making quality-assessed data available in real-time or near real-time.

5.3.2.4. Lightning detection systems

Ground-based (total or only “cloud to ground”) real-time lightning detection and tracking systems have demonstrated their value as an early indicator of the location and intensity of developing convection, and also of the motion of thunderstorms. Especially for nowcasting, severe weather warning and aviation applications, these observing systems may increase the warning lead time associated with severe thunderstorms. For aviation the data coverage requirement is almost global. Advanced lightning systems also provide the 3D structure of the electricity activity for aviation.

In 2025 one can foresee long-range lightning detection systems providing cost-effective, homogenised global data, with a high location accuracy, significantly improving the data coverage in data-sparse areas. High resolution lightning detection systems should be also deployed in some specific areas, for special applications, with higher location accuracy, and with cloud-to-cloud and cloud-to-ground discrimination.

Action G34

Action: Improve global lightning detection efficiency by extending the deployment of long-range lightning detection systems and introducing more of these systems. Priorities should be given to filling gaps in populated areas and along commercial airline routes.
Who: NMSs / NMHSs and agencies operating long-range lightning detection systems RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.
Time-scale: Continuous.
Performance indicators: Data coverage for this type of observations.

Action G35

Action: Develop and implement techniques for the integration of lightning detection data from different systems, including from surface and space-based systems, to enable composite products to be made available.

Who: NMSs / NMHSs and agencies operating lightning detection systems, RAs and TCs, coordinated by CBS and CIMO, leading the action jointly.
Time-scale: Continuous.
Performance indicators: Level of integration of the lightning systems.

Action G36

Action: Improve the exchange of lightning detection data in real-time by establishing and implementing agreed data licensing protocols for the exchange of data.
Who: NMSs / NMHSs and agencies operating lightning detection systems, NMSs, NMHS, RAs and TCs, coordinated by CBS and CIMO, both .
Time-scale: Continuous.
Performance indicators: A percentage of observations exchanged regionally and globally.

5.3.2.5. Surface-based stations serving specific applications

Many specific observing networks have been developed (and are still being developed) to monitor local applications such as the weather variables alongside the roads, motorways or railway tracks, within and around cities and airports, within agro fields or those needed for electrical plants. This ensemble of networks is very heterogeneous in terms of observed variables, observing practices, standards, as well as frequency of observations. However these data are essential elements for meeting climate service requirements and are very useful not only for their main application but also for many other larger-scale applications documented in the RRR, including for global and high resolution models.

In the coming years, specific attention needs to be paid to the measurements in the urban environment, for at least two reasons: (i) The monitoring of the climate variability and change is important in such areas where specific issues of adaptation arise; (ii) The verification and validation of local NWP and air-pollution models which are likely to be run operationally over limited areas centred over big cities; these models are likely to become an important instrument of the climate variability and change monitoring in addition to their role in meteorological and air-pollution short-range forecasting.

Such specific observations and models are likely to be needed not only in the vicinity of big urban agglomerations, but also in the vicinity of important airports, where the aviation requirements may imply the development of specific high resolution networks for monitoring and nowcasting severe phenomena.

Most of these specific observing systems are fully automatic, they use up-to-date technologies and often produce observations with high frequency. In order to have these systems serving a wider range of users, there should be a coordinated planning on appropriate data representation and codes and reporting practices, approved QM/QA[31] standards for data and metadata. In addition, standards should be developed for the data processing in order to produce derived sets of observations required by different users (local, national, regional, global).

Observing systems can also be leveraged for support of renewable energy sources. For the clean energy sources (wind, solar, hydroelectric, geothermal energy), climate information is an essential part of development activities, and they require a continuing assessment of efficiency and environmental impacts.

Comment [ajs41]: But forecast information is also needed

Action G37

Action: Ensure, as far as possible in real-time, exchange of observations made by surface-based stations serving specific applications (road transport, aviation, agrometeorology, urban meteorology, etc.) and develop a processing system for their integration and re-processing to serve multiple applications.

[31] Quality Management and Quality Assessment

Who: Agencies operating stations serving specific applications, NMSs / NMHS, RAs and TCs, coordinated by CBS.
Time-scale: Continuous.
Performance indicators: A percentage of observations from the above stations exchanged regionally and globally in real-time.

Action G38

Action: Enhance observations in candidate areas to support studies associated with the development of renewable energy technologies, and also to understand the influence of renewable energy sources on local weather and climate phenomena related to the operation of the renewable technologies.
Who: Agencies operating stations serving renewable energies, NMSs/NMHS, RAs and TCs, coordinated by CBS.
Time-scale: Continuous.
Performance indicators: Number of observations supporting research and development of renewable energies.

Comment [ajs42]: Why just R&D? Why not operations also?

5.3.3. Hydrological observing systems over land

5.3.3.1. Hydrological reference stations

Concerning the global exchange of hydrological variables, GCOS, through its co-sponsored Terrestrial Observation Panel for Climate (TOPC), has established the Global Terrestrial Network for Hydrology (GTN-H), with the objective of designing and implementing the baseline networks, and in order to demonstrate the value of integrated global hydrological products. The activities of the GTN-H and of the WMO/CHy include the global monitoring of rivers, lakes, ground water and water use. The monitoring programmes' requirements led to the establishment of GCOS/GTOS baseline networks for river runoff and lake level.

The Global Runoff Data Centre (GRDC) has a mandate to collect river discharge data, but long delays can occur before the data are actually collected and distributed. In addition there is a tendency to reduce the number of stations in the existing observing networks, and there is a strong concern over this continuous decline of hydrological networks, especially the closure of climate-relevant stations.[32]

Action G39

Action: For climate purposes, maintain the existing hydrological stations of the GCOS/GTOS baseline network, and organize their global exchange.
Who: All hydrological services operating these reference stations, WMO commissions (CHy and CBS), GCOS. CBS and GCOS to lead the action.
Time-scale: Continuous.
Performance indicators: percentage of hydrological reference stations exchanging globally quality-assessed data.

More details about specific actions on hydrological reference stations can be found in relevant sections of the GCOS-IP. A general description of all the elements contributing to hydrology, water resources and water cycle can also be found in the WHYCOS document[33].

5.3.3.2. National hydrological network stations

For monitoring the Earth water cycle, many variables are measured by national hydrological networks and other stations from heterogeneous networks: precipitation, snow depth, snow water content, lake and river ice thickness, dates of freezing and break-up, water level, water flow, water

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[32] See the paragraph on the exchange of hydrological data in the GCOS-IP.
[33] http://www.whycos.org/IMG/pdf/WHYCOSGuidelines_E.pdf

quality, soil moisture, soil temperature, sediment loads. Some of them are not relevant to any real-time applications, but some others require a rapid data exchange (e.g.: precipitation and river discharges in case of flood event). A small subset requires global exchange whereas most of them need to be exchanged only at the national and local level.

The TOPC has identified hydrometeorological variables with a high observation priority.[34] Several of these variables have an in-situ observation component which is complemented by a satellite component; still, there are important identified gaps in the different hydrology networks which have to be filled. In general there is an insufficient access to hydrological variables.

The observation of hydrological variables on global and regional scales, performed in a continuous and consistent way will require integrated observing systems (both in-situ and satellite-based) and used in support of several application areas. Observations include those of hydrological variables such as evaporation, soil moisture, snow, and surface and groundwater, as defined in GCOS-IP terrestrial actions.

Action G40

Action: Include observations of key hydrological variables (precipitation, evaporation, snow depth, snow water content, lake and river ice thickness, water level, water flow, soil moisture) into an integrated system for a consistent observation, processing and exchange, following the WIGOS standards.
Who: Hydrological services, GCOS, WMO commissions (CHy and CBS) leading the action .
Time-scale: Continuous.
Performance indicators: percentage of hydrological data integrated in this system.

5.3.3.3. Ground water stations

Ground water has an important role in the environment and its management, although it is less important for many applications covered by the RRR (especially the forecasting applications). It is used as primary source of drinking water and also in agricultural and industrial activities. Ground water resources need to be protected as, in many regions, withdrawal rates exceed recharge rates. Once modified or contaminated, ground water can be very costly and difficult to restore.

Ground water monitoring is a continuous standardized process involving in-situ, satellite and air-borne observations. The groundwater monitoring includes both its quantity and its quality (analysis of selected physical and chemical variables).

According to a world-wide inventory of ground water monitoring compiled by the International Ground water Resources Assessment Centre (IGRAC), in many countries, a systematic monitoring of ground water quantity and quality is minimal or non-existing.

Action G41

Action: To continue and expand existing programmes of ground water observation and monitoring, including expansion of the IGRAC.
Who: Hydrological services in collaboration with WMO/CHy, the Food and Agriculture Organization (FAO) and GTOS (especially its Global Terrestrial Network for Groundwater - GTN-GW – component). WMO/CHy and GTOS to lead the action.
Time-scale: Continuous.
Performance indicators: number of ground water stations operating.

The ground water actions described in the GCOS-IP should be supported, especially those aimed at establishing a prototype global monitoring information system with the GTN-GW.

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[34] See SoG on Hydrology

5.3.4. Weather radar stations

Weather radars are acquiring an increasing importance in weather forecasting and warning, in hydrology and many applications depending on weather forecasting. This increased importance is partly related to the development of NWP models at kilometre scale (which progressively become able to assimilate weather radar data) and of other ad hoc tools for nowcasting and short-range forecasting. Weather radars have the capacity to observe several variables related to precipitation: precipitation intensity and geographical distribution, hydrometeor size distribution, phase and type of precipitation. They can also locate sand and dust storms, and they can measure wind components through the Doppler technique, and also humidity through the refractivity. The deployment of polarimetric weather radars contributes to the improvement of quantitative precipitation estimates (QPE), to a better detection of large hail, and to an improved identification of rain/snow transition regimes in winter storms. VHF radars have been tested and can provide observations at higher resolution, but only at shorter range. All these weather phenomena are especially important for aviation and severe weather forecasting and warning for public.

Advances in NWP, climate modelling, and severe weather warnings and disaster mitigation have led to new requirements for precipitation products of high quality constructed from data from one or more radar networks. Also, recent advances in radar technology and in signal and data processing have brought the field to the brink of operational readiness for these products and their quantitative use for various operational applications. In the past, radars were perceived to address only regional and local applications but this view is rapidly changing as telecommunication networks allow vast amounts of data to be transferred and archived.

The weather radar coverage was improved considerably during the last decades in some regions of the world, with some data exchanged across the national borders (on at least some composite products). For example, in Europe, the Operational Programme for the Exchange of weather RAdar information (OPERA) programme that is part of EUMETNET[35].

There is still a lot of potential progress which should come before 2025 from improved technology, standardization of observing procedures, and increase of data exchange, including at the global level. Currently (in 2012), in the areas that are well covered by weather radars, there is a lot of heterogeneity in technology deployed, the observing practices, the calibration and processing techniques, and the form of the data presentation and exchange. In the developing countries, the radar coverage is poor or non-existent, including in the areas where the storm nowcasting (and very short-range forecasting - VSRF) is extremely important. A special effort has to be organized for these areas, not only in terms of weather radar deployment, but also in terms of nowcasting tools combining a limited number of weather radars with other sources of information (satellite products, propagation of GNSS signals or of other electromagnetic signals).

Action G42

Action: Increase the deployment and use of dual polarization radars in those regions where it can be shown that clear benefits will be obtained.
Who: CBS to lead the action in collaboration with CIMO, RAs and NMSs / NMHSs.
Time-scale: Continuous.
Performance indicators: Data coverage obtained from this type of radar for each Region.

Action G43

Action: Perform comparison of weather radar software with the objective to improve quality of the quantitative precipitation estimates (QPE).
Who: CIMO in collaboration with NMSs / NMHSs and agencies operating weather radars.
Time-scale: Continuous.
Performance indicators: Guidance provided to the manufactures and Members.

[35] http://www.eumetnet.eu/

Action G44

Action: For areas in developing countries which are sensitive to storms and floods, a special effort has to be made to establish and maintain weather radar stations.
Who: NMSs / NMHSs, agencies operating weather radars, in collaboration with RAs and Technical Commissions (CBS, CIMO and Chy). CBS to lead the action with each RA.
Time-scale: Continuous.
Performance indicators: The number of operational weather radar stations in the above areas.

Concerning the use and impact of observations in NWP, the Proceedings of the 2008 WMO workshop states (see reference in footnote 20 of section 4): "Radar data have demonstrated their positive impacts on regional data assimilation systems, and on some occasions also on global systems". By 2025, it is expected that most of the operational global data assimilation systems for NWP (and re-analyses) will assimilate some radar data, at least in the form of Doppler winds. Therefore, a global exchange of selected radar data should be introduced.

Radar information is also important for climate applications. It will be used in the future for (e.g.) regional re-analyses and monitoring of the water cycle. See GCOS-IP – executive summary.

Action G45

Action: Define weather radar data to be exchanged at regional and global levels, propose frequency of exchange of those data and develop a weather radar data processing framework, in concert with development of products based on national, regional, global requirements.
Who: CBS (leading the action), CIMO, CHy in coordination with NMSs/NMHSs, agencies operating weather radars, in collaboration with RAs.
Time-scale: Continuous.
Performance indicators: Volume of radar data which are exchanged globally and regionally.

5.3.5. Upper-air observing system over the oceans. Automated Shipboard Aerological Programme (ASAP) ships

All the Actions documented in section 5.3.1 related to radiosonde observations over land, except those for GRUAN (5.3.1.2), are relevant for ASAP platforms. These Actions refer to:

- the importance of isolated radiosonde data for removing the biggest gaps in data coverage;
- the appropriate coding of the total radiosonde information in the vertical, followed by a rapid real-time dissemination;
- the possibility to optimize the data coverage by adapting the launching time, taking into account the ensemble of the radiosonde network, but also other observation systems providing vertical profile observations (AMDAR for example).

- For the North Atlantic area (with very few islands which can provide fix radiosonde sites), EUMETNET (see footnote 35) has developed a European component of the Automated Shipboard Aerological Programme (ASAP), called E-ASAP (EUMETNET – ASAP). See information on E-ASAP by going to the home page of EUMETNET. Between 15 and 20 ships operate regularly radiosonde launches in the North Atlantic on commercial line services from western Europe to north and central America. These ASAP ships contribute to about 10 to 15 radiosonde observations per day on average (situation of 2012), most of these observations being made at 00 or 12 UTC (possibility to make them at a different time, in order to optimize space-time coverage). In the year 2011, the E-ASAP programme contributed about 4500 radiosonde launches over the Atlantic Ocean. Concerning the impact of ASAP ships on numerical forecasts, the Proceedings of the 2008 WMO workshop states (see reference in footnote 20 of section 4): "Even a very limited number of radiosondes located in data sparse regions in the oceans can have a significant impact on the forecast". The North Atlantic ASAP network has not only a direct impact on forecasts, but it helps the use of satellite data by providing in-situ reference observations with a lot of vertical details.

More than 80% of the total ASAP launches in 2011 were performed in the Atlantic Ocean. Therefore, for other oceanic areas, and especially for the North Pacific and Indian Ocean, there is potential for improving very significantly the overall quality of the composite observing system through the development of a very limited number of observing platforms (typically 10 or 20). Dropsondes launched from reconnaissance aircrafts are an equivalent system which is used both in the Pacific and in the Atlantic, but very irregularly, in anticipation of severe storms.

Comment [ajs43]: Only in anticipation, not when storms have become severe?

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- **Action G46**
  - **Action**: Maintain and optimize the existing ASAP network over North Atlantic, and develop similar programmes for the North Pacific and the Indian Ocean.
  - **Who**: NMSs, NMHSs, in collaboration with companies operating commercial ships, Regional Associations, CBS and CAS THORPEX regional committees. CBS and CAS/THORPEX to lead the action together with the NMSs and NMHSs which are in good position for identifying relevant shipping lines.
  - **Time-scale**: Continuous.
  - **Performance indicators**: Volume of ASAP data available in real-time (usual NWP monitoring indicators).

5.3.6. Surface observing systems over the oceans

The important ocean surface variables to measure are the surface pressure, the SST, the Sea Surface Height (SSH), the Sea Surface Salinity (SSS), the surface wind, the wave characteristics, the ocean surface current and the visibility. Additional variables are needed near the coasts and also when the ocean is covered with ice. For most of these variables, it is necessary to combine the in-situ and satellite measurements in order to get the best estimate.

Comment [j44]: Visibility is a surface air variable. either delate or include other surface air variables such as temperature and humidity

Comment [j45]: We could make such a statement almost everywhere. (It is a logical truth, not a statement of fact.) I suggest we delete it.

Comment [ajs46R45]: Does not apply to deep ocean.

The uneven geographical coverage of the in-situ ocean observing network is an ongoing issue for ocean applications. Considering the regional variability in requirements, varied deployment logistics (including from remote regions, and insecurity-prone regions), and the difficulty to ensure optimized planning for observing networks with limited resources, WMO Members should note the need for studies on geographical variability in spatial / temporal resolution for ocean observations.

Most of the actions documented in the following sub-sections are aimed at improving the geographical coverage of ocean observing systems, particularly for measuring surface pressure, SST, SSH, SSS and visibility, along with higher resolution geometry. This can be done by extending open-ocean and coastal observing networks, or developing existing observing sites into multi-purpose stations, or also using emerging remote-controlled in-situ observation technologies to cover inaccessible regions.

5.3.6.1. High Frequency (HF) coastal radars

HF coastal radars are a very powerful observing technique for monitoring the sea state and the surface ocean current within a few hundred kilometres of the coasts. These radars can measure both waves (significant height) and current within a kilometric horizontal resolution. For many of the HF radar systems now in use, a triangulation technique using two radars is required to remove directional ambiguities in waves and currents.

The purpose of this radar observing system is not to achieve a good global coverage of the ocean coasts, but to improve the horizontal resolution and the quality with respect to other oceanic observations in the coastal areas which are very sensitive to the weather and oceanic phenomena (for environmental or economical reasons): populated areas near the coasts, harbours with a lot of ship traffic, risk of pollution (for both the terrestrial and the marine wildlife). By 2025, it is likely that specific atmospheric and oceanic Limited Area Models (LAM) will be operated on many coastal areas with a horizontal resolution between 100 and 1000m, in order to help the real-time monitoring of these sensitive areas. HF coastal radars should then become an important source of information to be assimilated in these models. They are already an important source of information for the production of real-time maps of ocean surface currents and significant wave height for ship traffic and for search and rescue operations.

5.3.6.2. Sea stations (ocean, island, coastal and fixed platforms)

The synoptic sea stations provide observations of the same surface variables as land surface synoptic stations (see 5.3.2.1): surface pressure, temperature, humidity, wind, visibility, cloud amount, type and base height, precipitation, past and present weather. With respect to land surface synoptic stations, their role is increased for two reasons:

- They also observe a set of marine variables: SST, wave direction, period and height, sea-ice, etc.
- They are generally situated either in sensitive coastal areas or on isolated sites like islands and oil platforms, and so they are more important in terms of their contribution to global data coverage.

The recommendations of section 5.3.2.1, valid for land surface synoptic stations, apply also to synoptic sea stations. The isolated islands which have already a long climate record are particularly important to maintain for climate monitoring.

- The sea station networks are very insufficient to meet the different marine and oceanic requirements, especially for SSH, SST, SSS, and wave measurements.[36] A general improvement in measurement capabilities and data accessibility is needed, which has to rely not only on sea stations, but also on ships, buoys, tide stations and profiling floats.

- **Action G47**
  - **Action**: Ensure state-of-art technologies are employed to improve accuracy for all measurements made at sea stations. Develop visibility measurement capabilities over the ocean (consultation needed with JCOMM experts on how to practically achieve this).
  - **Who**: NMSs, NMHSs and national partner institutions, in collaboration with international organizations and space agencies. JCOMM, CBS, and CIMO to lead the action..
  - **Time-scale**: Continuous.
  - **Performance Indicator**: Usual monitoring indicators on availability and quality of marine observations.

5.3.6.3. Voluntary Observing Ships Scheme (VOS)

The list of meteorological and marine variables which is normally observed by VOS ships is the same as the one observed by sea stations (5.3.6.2.). The main practical difference is that ships are mobile platforms: this can be an advantage for a better space-time data coverage, but it is a drawback for climate users interested in long time series.

Many recommendations made for land surface synoptic stations are also valid for ships, especially those concerning: global exchange of hourly data (G27) and coding and transmission of metadata (G29). For the atmospheric pressure measurement onboard ships, a particular attention should be given to the barometer height, its correct value, correct coding and correct transmission. Indeed atmospheric pressure (often reduced to sea level in this case) is the most important ship observation for NWP, and it is also very important for marine and aviation applications, as well as synoptic meteorology and nowcasting. The global NWP monitoring of ship data shows that some ship observations are affected by important biases in atmospheric pressure measurements, which is obviously linked to incorrect barometer heights (and/or erroneous reduction to sea level). There are also potential improvements on the quality of ship air temperature, SST and wind observations,

[36] See SoG on Marine Applications)

improvements which could be obtained by more regular interactions of the observation operators with the NWP monitoring centres. See for example the ECMWF web site[37]

Action G48

Action: Improve the quality of ship observations by more regular interactions with the NWP monitoring centres and more regular checks on the instruments onboard.
Who: Port Meteorological Officers (PMOs), NMSs, NMHSs and other NWP monitoring centres in collaboration with companies operating commercial ships. CBS and JCOMM to lead the action.
Time-scale: Continuous.
Performance indicators: Usual NWP monitoring indicators.

5.3.6.4. Moored and drifting buoys

The moored and drifting buoys normally provide observations for a subset of the following variables: surface pressure, temperature, humidity, wind, visibility, SST, ocean current, 3D wave spectrum, wave direction, period and height, precipitation. As they are fully automatic systems, this observed subset is reduced compared to what can be observed by ships or synoptic sea stations (e.g.: clouds and present/past weather are not observed by buoys). There is a large variety of buoys which are deployed operationally, and sometimes the observed subset is reduced to one or two variables on the simplest buoy types. The advantage of the fully automatic systems is that the observation frequency can be quite high for some buoys (observed data every 10 minutes, for example). Drifting buoys move away from their deployment point shortly after being put into the water. They have a limited operational lifetime for reasons such as battery life, sensor failure, transmitter failure, running ashore, etc. The Data Buoy Cooperation Panel (DBCP) of JCOMM strives to maintain a global network of 1250 drifting buoys deployed to meet a grid spacing of 5 degrees by 5 degrees. New buoys have to be redeployed regularly to maintain oceanic data coverage which is complemented by ship data coverage (commercial sailing lines). For the mid-latitude part of the north Atlantic, a good data coverage (and a good complementarity with ships) has been achieved in the years 2000-2010 mainly through the EUMETNET Surface Marine Programme (E-SURFMAR[38]). However continuous efforts are needed to maintain this coverage, it is still below the requirements in some small areas of the North Atlantic where the deployment is difficult. In addition, in many other areas of the globe, the buoy data coverage is not as good, it presents significant gaps in (e.g.) the southern oceans and the North Pacific. The operational data coverage (for buoys and other observing systems) can be checked on a daily basis on (e.g.) the ECMWF web[39]. The maps showing the monthly buoy coverage (for different types of instruments, different observed variables) can be seen on the DBCP web[40].

For NWP, the most important variable (among those observed by buoys) is surface pressure, and it is important to improve its data coverage. In data assimilation it is used in synergy with space-based surface wind measurements (scatterometers, microwave instruments). A good SST global coverage is important both for NWP and ocean applications. Ocean current information is valuable for oceanographic analysis and forecasting. The wave information is very important for marine services and applications.

Moored buoys provide a richer and more geographically stable data set than drifting buoys for climate time series which are difficult to build with moving platforms. However, even for climate monitoring, the drifting buoys contribute indirectly through their use in meteorological and ocean data assimilation, and in the re-analyses.

[37] http://www.ecmwf.int/products/forecasts/monitoring/mmr/Global_monitoring_statistics.html
[38] http://www.eumetnet.eu/Surfmar.htm
[39] http://www.ecmwf.int/products/forecasts/d/charts/monitoring/coverage/dcover/
[40] http://www.jcommops.org/dbcp/

The recommendations G27, G28 and G29 made for synoptic sea stations do apply for moored and drifting buoys. The global collection and exchange of buoy observations should be hourly as a minimum. It is recognized that the limitations of satellite telecommunications limit the timeliness of data collection for a significant number of drifting buoys.

Given the importance of a good atmospheric pressure data coverage and of the technological capacities for measuring pressure, the recommendation of GCOS-IP on buoys should be strongly supported. It calls for the implementation of pressure sensors on all the buoys by 2014. Another GCOS recommendation which should be supported calls for all the buoys of the Ocean Reference Mooring Network (a data buoy subset of the Ocean Sustained Interdisciplinary Timeseries Environment observation System - OceanSites[41]) to be equipped with precipitation measurement instruments. Observations of precipitation are particularly important for the interpretation of satellite data over the oceans. The GCOS recommendation for the implementation of a wave measurement component as part of the Surface Reference Mooring Network is important because of the limited number of marine reference sites providing information on the waves and because of the limitations of satellite-based wave measurements.

In summary, ocean buoy data are useful for weather and ocean forecasts and for climate monitoring, and additionally can be used to complement or validate remotely-sensed data and operational models.

Action G49

Action: Support the DBCP in its mission to maintain and coordinate all components of the network of over 1250 drifting buoys and 400 moored buoys, which provides measurements such as sea-surface temperature, surface current velocity, air temperature and wind speed and direction.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.
Time-scale: Continuous.
Performance indicators: Volume of quality-controlled moored and drifting buoy data available in real-time (usual NWP monitoring indicators).

Action G50

Action: Install barometer on all newly deployed drifting buoys.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.
Time-scale: Continuous.
Performance indicators: Availability of surface pressure observations from drifting buoys.

Action G51

Action: In the tropical Indian Ocean, extend the existing network of moored buoys to a data coverage similar to those of the Atlantic and Pacific tropics.
Who: NMSs, NMHSs, national oceanography institutions, in collaboration with JCOMM, international organizations and companies operating oceanic buoys, CBS and CIMO. CBS and JCOMM to lead the action.
Time-scale: Continuous.
Performance indicators: Number and data coverage of moored buoys available in the Indian Ocean tropics (usual monitoring indicators).

5.3.6.5. Ice buoys

[41] http://www.oceansites.org/

Ice buoys observe some of the following variables: surface pressure, temperature, wind, ice thickness, and upper ocean temperature and salinity. Sea ice motion is derived from their movement. Some buoys measure only air temperature, surface pressure, and position (therefore motion). More robust measurements are made by ice mass balance (IMB) buoys, which can measure snow depth, ice thickness, the ice temperature profile, ice motion, and some meteorological variables. In 2011, about 25 buoys were in service at any time, though fewer than ten measure ice and snow thickness. As with buoys deployed in the open ocean, surface pressure is a very important variable for NWP, and this is especially true for the northern polar cap which is otherwise a gap in the data coverage. Ice thickness, snow depth, and temperature are also key variables to monitor in the context of climate change, and also for many marine applications.

Comment [j47]: Check my proposed change here

Action G52

Action: Increase ice buoy data coverage on the northern polar cap through a regular deployment of new drifters.

Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating ice buoys, CBS and CIMO. CBS and JCOMM to lead the action.

Time-scale: Continuous.

Performance indicators: Volume of ice buoy data available in real-time (usual NWP monitoring indicators).

5.3.6.6. Tide stations

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- They measure the sea water height. In some cases other variables such as surface pressure, wind, sea water temperature and salinity are measured at the same site. The main role of the Global Sea Level Observing System (GLOSS) is to provide oversight and coordination for global and regional sea level networks in support of oceanographic and climate research related to tide and mean sea level applications (both real-time and not real-time). The main component is the GLOSS Core Network (GCN), an evenly distributed set of about 300 coastal and island tide gauge stations that serves as the backbone of the global network.

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- There is a need to complete and sustain the GCN network of tide gauges to monitor the coastal sea level changes. The GCN stations should be linked to continuous GNSS stations where possible (either directly at the gauge or levelling to nearby continuous GNSS stations) to enable determination of vertical land motion near GCN stations and thereby absolute sea level change. This is important in the context of the climate change to support the adaptation planning. In this context, the recommendation in the GCOS-IP concerning the GCN should be supported.

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- The GCN remains a main focus of the GLOSS programme. Stations at roughly 1000 km intervals along the continental margins and at all the major island groups provide sufficient global coverage for a range of oceanographic applications. A denser station network is typically needed for regional/local applications. When instruments are renewed or upgraded multiple use of the sea level stations should be considered where possible (i.e. tsunami, storm surge and wave monitoring).

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- **Action G53**
  - **Action**: Ensure global availability of tide gauge data.
  - **Who**: NMSs, NMHSs, and national partner institutions, in collaboration with international organizations and space agencies. JCOMM, CBS, and CIMO to lead the action..
  - **Time-scale**: Continuous.
  - **Performance Indicator**: Amount of tide gauge data available globally.
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5.3.7. Sub-surface oceanic observing systems

5.3.7.1. Profiling floats

In the ocean sub-surface, profiling floats measure some of the following variables: temperature, salinity, dissolved oxygen and CO_2 concentration. The Argo[42] profiling floats provide global coverage of temperature and salinity profiles down to 2000m. “Deep-Argo” floats are under development and will be able to go deeper. Data are assimilated in ocean models and used for Seasonal to Inter-Annual (SIA) forecasts, for monitoring the ocean sub-surface and for other marine applications. Higher resolution in the observing network would be needed in some active oceanic areas. Some of these profiling float data are also delivered with delays which are inadequate for real-time applications.

Comment [ajs48]: Rather a bland statement. It would be better give an indication of how much deeper.

Action G54

Action: For ocean and weather forecasting purposes, improve timely delivery and distribute high vertical resolution data for sub-surface temperature and salinity from profiling floats.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with Argo project, JCOMM, international organizations and companies operating profiling floats, CBS and CIMO. JCOMM to lead the action in cooperation with CBS.
Time-scale: Continuous.
Performance indicators: Volume of profiling float data available in real-time (usual monitoring indicators).

The important actions of the GCOS-IP (concerning profiling floats) should be strongly supported: (i) the appropriate number of floats required for enhancing and sustaining an adequate network, (ii) a pilot project for putting oxygen sensors on some floats. The main reason is the need to monitor carefully the quantity of dissolved oxygen in the oceans, in relation with the climate evolution and the impact on ocean biochemistry and marine life.

5.3.7.2. Ice tethered platforms

The ice-tethered platforms move at the speed of the ocean ice cover (slowly) while observing the temperature, the salinity and the current underneath. Because of the lack of other techniques for monitoring the deep polar oceans that are frozen at the surface, the ice-tethered platforms have an important role with respect to the global data coverage of oceanic data.

In the context of research projects dedicated to the Arctic Ocean, CO_2 and CH_4 sensors have been also used on ice-tethered platforms. [43]

5.3.7.3. Ships of opportunity

Comment [ajs49]: Why discuss only ships of opportunity? What about repeat lines by dedicated oceanographic vessels, as in the GOSHIP programme?

With XBT instruments, ships of opportunity can provide oceanic temperature profile data with a good vertical resolution (about 1m) down to 1000m. They are used by several applications in the same way as profiling floats (see 5.3.7.1), and there is also a lot of potential to improve their real-time delivery.

Action G55

Action: For ocean and weather forecasting purposes, improve timely delivery and distribute high vertical resolution data for sub-surface temperature from Ships/XBT.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating ships of opportunity, CBS and CIMO. JCOMM to lead the action in cooperation with CBS.

[42] http://www.argo.net
[43] http://www.whoi.edu/science/PO/arcticgroup/projects/ipworkshop_report.html

Time-scale: Continuous.
Performance indicators: Volume of XBT data available in real-time (usual monitoring indicators).

The action of the GCOS-IP, aiming at improving and sustaining the existing network and coverage of the ships of opportunities should be supported.

5.4. Research & development and operational pathfinders

Research efforts are ongoing to observe better details of the atmospheric boundary layer, and these efforts are likely to be required for several years in this area. The observation requirement is primarily for wind, temperature and humidity profiles. It is also for aerosols, some chemical species and cloud properties. Indeed, the lack of detailed vertical profiles in the boundary layer (especially wind profiles) is one of the big weaknesses of the current GOS, it is probably the biggest gap which appears by comparing the RRR with the current observing facilities (see for example the SoG for global NWP). For temperature, water vapour and other atmospheric gases, satellite sounders are either unable to observe the boundary layer profiles because of inadequate vertical resolutions, and often also (for infra-red sounders) because of the presence of clouds. (See, for example, the user requirements and SoGs for high resolution NWP, nowcasting and aviation). The only routine surface-based observing system which has currently the capacity of measuring the boundary layer profile is the radiosonde network, but with severe limitations on the data coverage and on the observation frequency (every 12h most of the time). Ground-based wind profilers and profiling stations integrating wind, temperature and humidity are the best hope for high frequency observations of the boundary layer, at least locally, and perhaps also at the regional level, but research efforts are still needed before the implementation of operational networks. Technological progress for profiling techniques is also dependent on the existence of a small number of reference observatory stations, as suggested by GCOS with the GRUAN. Long periods of inter-comparisons between reference stations and new types of profilers are sometimes necessary to calibrate properly the new instruments (see 5.3.1.2). The CIMO Testbed and Lead Centres sites will contribute to improve the performance of profilers in the atmospheric boundary layer, see:
http://www.wmo.int/pages/prog/www/IMOP/Testbeds-and-LC.html

There are at least two other domains which are poorly observed with respect to the RRR and where technological developments are needed to achieve significant progress:

- In the atmosphere, a better observation of clouds (with their large variety of water and ice particles – especially important for aviation), of aerosols and chemical species. It is important that manual cloud observations should be continued at representative stations. Manual observations need to be retained at least until technological advances are sufficient to ensure automated measurements can satisfactorily replace manual observations.
- In the ocean sub-surface, where it is difficult to obtain any observation at all, ocean gliders and instrumented marine animals are two observing options which are in development (see 5.4.5 and 5.4.6 below). The GCOS recommendation about promotion of new improved technologies, in support of the GOOS for climate applications is the important one to activate.

Comment [ajs50]: What is meant by this? It rather downplays what has been achieved with Argo.

Another general tendency affecting meteorological and environmental observations is the move to more automatic and highly computerized systems. It leads to the production of more frequent data and higher volumes of raw data. The pre-processing of the observations tends also to become fully automatic. This requires higher integration between the observation and the data processing. In order to satisfy different types of user, the observation pre-processing will become more complex and more flexible, and it will follow the same tendency as the satellite data: the necessity to produce 2 or 3 different levels of data for different users. The levels will differ by the amount of pre-processing applied to the raw data and by the data volume.

The tendency to more automation is a factor which contributes to a tendency towards “more observing systems of opportunity”. The best example of opportunity in meteorology (which came in the 1990s and the first decade of this century) is the use of GNSS signals propagating through the atmosphere to extract meteorological information. If research actions are carried out towards new opportunities, one can expect the development of other surface-based observing systems based on technologies and capabilities which are designed primarily for non meteorological purposes. Basically, many telecommunication signals propagating in the atmosphere are potentially able to bring indirectly information about the atmospheric state. This has been already successfully tested for estimating the precipitation rate from the attenuation of the Global System for Mobile Communications (GSM) signals of mobile telephones, see Messer (2007). Windmills used for electricity power production is another potential opportunity for getting local information on the wind. The electricity power production is obviously dependent on the wind, then this dependence can be inverted in a way that derives the wind information from the power production. In addition, an ensemble of windmills is an opportunity to have a 100m mast which can be instrumented with meteorological sensors at different heights, to provide high vertical resolution profiles from the first 100m in the atmospheric boundary layer. Such an action requires a co-operation between the wind turbine operators and instrument experts from NMSs or NMHSs.

Comment [j51]: Is this the correct term? (also 2 sentences down)

A third tendency for the period 2010-2025, which is true in many disciplines, is to obtain, transmit and use more and more information presented in the form of images. Intense weather phenomena, clouds, amount and type of precipitation on the ground (rain, snow, hail), visibility, sea state... are already exchanged on Internet through digital pictures or videos. Potentially they can provide the same information as the qualitative information which is in the SYNOP[44] code (with more details). However a lot of research and development is needed to exploit objectively this information which is generally not presented in a standard form, and which is difficult to quantify into environmental variables. This requires retaining manual capabilities at a sufficient number of stations both as a basic reference for representative stations, and for calibration purposes.

The technologies summarised below are observing systems that are still at the stage of research and development, and which could become part of global observing systems by 2025. This list is not intended to be comprehensive.

5.4.1. Unmanned Aeronautical Vehicles (UAVs)

UAVs have been used in several meteorological campaigns for obtaining detailed information on temperature, humidity and wind, on some limited geographical areas, in the lower troposphere. See Mayer et al. (2010). Unlike a normal aircraft, they can fly up and down, and they can provide vertical profiles of meteorological variables. As the atmospheric boundary layer is an important gap in terms of meteorological profiles, UAVs are well adapted to fill this gap locally, but they are difficult to use in routine mode.

UAVs could become an adaptive element of a composite observing system by 2025. Research has to be continued both on technological aspects and on the development of cost-effective means (for operating UAVs regularly). UAVs are also an excellent opportunity for integrating atmospheric chemical measurements and standard meteorological measurements on the same platform. Also aviation regulations need attention before UAVs can be used on a regular basis.

5.4.2. Driftsonde balloons (gondolas)

The driftsonde technique consists in launching a constant level balloon, flying in the stratosphere with several dropsondes (stored in a gondola) which can be dropped on demand, providing a vertical profile of temperature, humidity and wind (like normal radiosondes or dropsondes launched from an aircraft). They have been used in several meteorological campaigns, like the AMMA

[44] FM-12 SYNOP GTS format - Report of surface observation from a fixed land station

campaign in Africa (see footnote 24 in section 4) and the THORPEX/Concordiasi[45] experiment in Antarctica: see Rabier et al. (2010).

These gondolas look very well adapted to meteorological campaigns which are limited in time (a few weeks), but difficult to use in routine as a key element of the composite observing system (also because of the aviation regulations, like UAVs). Currently it is not possible to recommend any development plan for an operational use of this system.

5.4.3. GRUAN stations

The GRUAN is neither a new technology nor a new observing system. It is a concept initiated by GCOS (see section 5.3.1.1.2 of this report), consisting in maintaining a small number of observing sites (up to 40) operating high quality radiosondes, reaching the mid stratosphere (about 30 or 40 km as maximum height). In addition to their role in climate monitoring and as a reference for the GUAN stations, these observing sites should act as “small observation laboratories” in which atmospheric vertical profiles are observed through different techniques (surface-based sounders, profilers radars and lidars, etc.) and inter-compared. These atmospheric profiles should be as complete as possible and should integrate a larger number of variables (compared to ordinary radiosondes), including the measurement of clouds, aerosols and concentration of chemical species. Developing GRUAN sites is a simple way and a good opportunity to stimulate research on new observing technologies.

5.4.4. Aircraft atmospheric measurements

Automated aircraft measurements of wind and temperature have been operational in meteorology for more than two decades. Measurement of humidity from aircraft platforms commenced operations around 2010 (see 5.3.1.3).

Operational atmospheric chemistry measurements from aircraft platforms commenced around 2010 but are limited to a small number of aircraft and not integrated with the other meteorological measurements: see for example the documentation on the IAGOS project (IAGOS = Integration of routine Aircraft observations into a Global Observing System). Atmospheric composition measurements for several species, aerosols and volcanic ash are measured on some aircraft, but more in research than in operational mode. For the future it is important to converge to a more integrated operational system which would measure all these variables on some aircraft, process them consistently and make them available in real-time to data users, including Atmospheric Chemistry Models (ACM), aviation, global and regional NWP. As an illustration of the usefulness of this type of action, it has been shown that the numerical forecasts of some weather variables can be improved by treating the ozone variable in the NWP model through the assimilation of ozone observations. [46]

Action G56

> **Action**: Where possible and appropriate, integrate atmospheric composition measurements together with the measurements of wind, temperature and humidity, with processing and dissemination performed according to WIGOS standards.
> **Who**: Organizations involved in atmospheric measurements from aircraft platforms, NMSs, NMHSs in collaboration with commercial and other airlines and WMO commissions (CBS, CIMO, CAS) and AMDAR panel. CBS, CAS and AMDAR Panel to lead the action.
> **Time-scale**: Continuous
> **Performance indicators**: A number of aircraft producing both meteorological observations and atmospheric composition measurements in real-time.

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[45] Concordiasi is an international project of the THORPEX-IPY cluster within the International Polar Year effort to provide validation data to improve the usage of polar-orbiting satellite data over Antarctica

[46] See for example Semane et al. (2009).

Another source of important potential progress is the research and development actions associated with AMDAR systems for small aircraft, usually referred to as General Aviation (GA) aircraft (see 5.3.1.3). For example, the impact of existing data sets (derived from deployment of the commercial communications and sensor system, such as TAMDAR in the USA) on high resolution NWP models has been evaluated and compared to other observing systems such as profilers and radars. The results are encouraging: see for example Moninger et al. (2010) and Benjamin et al. (2010). In spite of several technical snags, AMDAR systems for General Aviation (GA) aircraft do have potential for contributing to the improvement of data coverage of vertical profiles of AMDAR measurements (wind, temperature, humidity, turbulence and icing) in the lower troposphere and this development should be pursued whilst taking into account the potential associated with new and developing technologies such as ADS-B and Mode S.

5.4.5. Instrumented marine animals

Marine animals provide opportunities for oceanographers to make observations, in the sense that the ensemble of sensors attached to an animal moving in the sea can be used for observing both the animal itself and its environment. Boelhert et al. (2001) stated: “Biological autonomous sampling systems have immense potential to contribute oceanographic data in a cost-effective manner”. Ten years later, around 2010, only modest progress has been noted in the use of this technique, which is limited by its lack of time continuity and its poor data coverage (limited to some coastal areas). Efforts should continue, especially to improve the exchange of data with all the users of ocean measurements, to make it more rapid and more standard.

5.4.6. Ocean gliders

The observing role played by UAVs in the atmosphere is similar to the one taken by ocean gliders in the ocean. This type of observations has been used in the past for oceanographic campaigns: see Rudnick et al. (2004) and Davis et al. (2002). They have the same capacity and the same flexibility to target a specific area of the ocean and to observe it in its 3 dimensions. Wave gliders and ocean gliders have been used in several field experiments. Wave gliders could be used on a routine basis in some parts of the world by 2015.

Research and developments should be pursued in at least two directions: on new instruments able to observe more ocean variables, and on the standardization of the data exchange.

6. Space-based observing system

6.1. Introduction

For several decades two types of satellites have been used in meteorology: geostationary satellites (GEO) and polar orbiting satellites (LEO: Low Earth Orbiting). The geostationary satellites are deployed along the equator, with their longitudes chosen to optimize the data coverage. The main advantage of a GEO satellite is the high observation frequency of 15 or 30 minutes. The main drawback is that it cannot observe the polar caps (polarward of about 60° of latitude). LEO satellites are generally deployed on a polar sun-synchronous orbit. Their main advantage is the global coverage which can be achieved in 12h with many scanning instruments. The data coverage is quite good near the poles where new observations can be produced at each orbit (i.e. about every 100 minutes). The main drawback is the observation frequency in low latitude regions, where observations are produced generally every 12h for a single platform. A rapid and continuous data collection by the ground segments is also more difficult to organize than for geostationary satellites.

Some satellite series have been operational for several decades, like the American Geostationary Operational Environmental Satellite (GOES) or the European METEOSAT (geostationary satellites), or the American NOAA[47] series of polar orbiting satellites. The main instruments operated on these operational satellites are imagers (visible and infra-red) and atmospheric sounders (infra-red or microwave). Research satellites have played a major role in complementing operational satellites, and they will continue to play a major role in the future, although they cannot guarantee the continuity of observation. Some platforms have different instruments serving different applications, and the tendency to develop multi-user platforms is likely to continue. Some user requirements will be met through constellations of satellites (e.g. the COSMIC[48] constellation for radio-occultation measurements). The data volumes and the variety of instruments which are used routinely for many applications have been increased considerably over the last 20 years. Nowadays, many satellite observing systems (including research satellites) bring a very significant contribution to operational weather and climate monitoring. Data continuity, which is essential for climate monitoring as well as for operational applications, is being threatened by the potential end of satellite missions before follow-on platforms are launched. Space agencies are encouraged to prolong the lifetime of currently flying instruments on relevant satellite missions.

A detailed description of the current satellite (and instruments) contributing to global observing systems (or are likely to contribute in the period 2012-2025) can be found in the WMO satellite "Dossier"[49]. One chapter of this document set addresses the "gap analysis", i.e. the more critical gaps which lead to recommendations on the development/improvement of satellite observing systems. Information on the different instruments and satellite programmes can be found in other chapters of the Dossier. For the coming 15 years, one can expect an expanded space-based observing capability, an expanded community of space agencies contributing to WMO programmes and an increased collaboration between them. One can expect also a tendency to have more and more satellites serving several applications.

Requirements for instruments on new satellite missions should be more and more developed as a result of the gap analysis of the integrated global observing system in order to make the global observing system as cost-effective as possible. This requires a fundamental re-analysis of capabilities of satellite-based systems against surface-based systems.

Comment [j52]: I propose we delete this. The first sentence is just a restatement of the aim of the RRR process, discussed previously. I disagree with the last sentence - we've done the analysis requested in the development of the Vision for the GOS.

In the following section (6.2), the generic issues concerning the space-based component of global observing systems are described, with the corresponding recommendations appropriate for implementation in the period 2012-2025. Section 6.3 describes the recommended Actions for the different observing systems classified in the following components (as foreseen in the Vision 2025):

- operational geostationary satellites (sub-section 6.3.1);
- operational polar-orbiting satellites on sun-synchronous orbits (6.3.2);
- other miscellaneous operational satellite missions, with various instruments on various orbits (6.3.3), which complement the two previous components, the ensemble being the backbone of the space-based observing systems;
- R&D satellite missions, operational pathfinders and technology demonstrations (6.3.4) whose role within composite observing systems in 2025 is uncertain, but which are likely to have an operational contribution by then;
- observations for space weather (which are discussed separately in section 6.3.5).

6.2. Generic issues: data calibration, data exchange

There will be a tendency towards higher spatial, temporal and spectral resolution for all satellite observing systems. It will enhance the information available, particularly to monitor and predict rapidly-evolving small-scale phenomena. It will increase the demand on data exchange and on processing capabilities. The spatial, temporal and spectral resolutions of the satellite data used in operational forecasting is generally coarser than the resolutions of the instruments, because of

[47] National Oceanic and Atmospheric Administration (USA)
[48] Constellation Observing System for Meteorology, Ionosphere and Climate
[49] http://www.wmo.int/pages/prog/sat/Refdocuments.html#spacebasedgos : this WMO web page contains a comprehensive dossier on past, present and future satellites with their instruments.

limitations in computer resources and in data assimilation methodologies. The resolution of the satellite data which are actually assimilated in meteorological and oceanic models is expected to increase faster than the instrument resolutions, by 2025, because of improvements in data assimilation techniques.

The progress on instrument capabilities and on the use of satellite information will be fully successful only if it is accompanied by actions aiming at improving the availability and the timeliness of the data for the different users and the different applications, from global assimilation in meteorological or oceanic models to the local use in nowcasting. This is more critical for LEO satellites than for GEO, but improvements have already been achieved through the development of the RARS (Regional ATOVS[50] Re-transmission Systems) which should continue in the future. This type of "quick re-transmission" action on satellite radiances for polar orbiting sounders has considerably helped NWP in the recent years, and it will help more and more regional and local forecast systems in the future. For GEO satellites, the data delivery is easier within the geographical area corresponding to the Earth disk which is observed directly by each satellite. The main challenge is the rapid processing and the rapid and global exchange of processed data (such as atmospheric motion vectors, AMVs) which are needed for global NWP with a hourly frequency at least.

Because almost all satellite instruments need other instruments or other measurements to improve their calibration, the role of the Global Space-based Inter-calibration System (GSICS) becomes increasingly important with the increase in the number of observing systems and in its variety. It is also essential to combine in-situ observations into the process of calibration, tuning and validation. These activities will be carried out by satellite agencies, national laboratories and major NWP centres, helped by WMO, CGMS and GEOSS. These activities cover:

- Earth-based reference sites (such as especially-equipped ground sites, ad hoc field campaigns...) used to monitor the satellite instrument performance.
- Extra-terrestrial calibration sources (sun, moon, stars) which are stable calibration targets for monitoring the instrument calibration.
- Model simulations which allow the standard monitoring comparison "observed values vs model values".
- Benchmark measurements of the highest accuracy by special satellite and ground-based instruments.

There should be common spectral bands on GEO and LEO sensors to facilitate inter-comparisons and calibration adjustments. Globally distributed GEO sensors should be routinely inter-calibrated using a given LEO, and a succession of LEO sensors in a given orbit should be routinely inter-calibrated with a given GEO sensor.

Action S1

Action: Maintain and develop the GSICS inter-comparisons and inter-calibrations between GEO and LEO sensors on an operational basis.
Who: GSICS.
Time-scale: continuous.
Performance indicators: quality of the calibrated satellite data as judged by the standard monitoring indicators.

Instruments should be inter-calibrated on a routine basis against reference instruments or calibration targets, using common methodologies. At least two Infra-red and two high-quality Visible and, ultimately, ultra-violet and microwave instruments should be maintained in LEO orbits to provide reference measurements for intercalibration of operational instruments in geostationary or LEO orbit.

[50] Advanced TIROS Operational Vertical Sounder

For most applications, and especially for climate monitoring, the time continuity of the key satellite sensors has to be planned and organized at the international level. In order to ensure continuity and consistency of data records, there is a need for (i) continuity of observations; (ii) overlap of key reference sensors that are needed to provide traceability, as articulated in the GCOS Climate Monitoring Principles (GCMPs) [51].

- **Action S2**
  - **Action**: Ensure continuity and overlap of key satellite sensors, keeping in mind both real-time processing and processing in delayed mode for consistency of climate records, re-analyses, research, recalibration or case studies.
  - **Who**: CGMS leading the action, with WMO commissions, satellite agencies and satellite data processing centres.
  - **Time-frame**: Continuous.
  - **Performance indicator**: Continuity and consistency of data records.
  -

6.3. Issues specific to each observing system component

6.3.1. Operational geostationary satellites

For geostationary meteorological satellites, one key feature is to have them distributed approximately uniformly along the equator, in order to have no gap between their respective observation disks in the tropics and mid-latitudes, so that they can provide a global, frequent (15-30 minutes) continuous data coverage, except for the polar caps (approximately poleward of 60° latitude). To meet the (current and future) different requirements, at least 6 operational geostationary satellites are needed, with no more than 70° longitude gap for their positions along the equator. During recent decades the continuity of coverage over the Indian Ocean has been the main concern. Currently, there is also a 80 to 85° gap along the equator between GOES-W and MTSAT.

- **Action S3**
  - **Action**: Ensure and maintain a distribution of at least 6 operational geostationary satellites along the equator, separated by no more than 70° of longitude. Improve the spatial and temporal coverage with GEO satellites over the Pacific.
  - **Who**: CGMS leading the action, with WMO commissions, satellite agencies and satellite data processing centres.
  - **Time-frame**: Continuous.
  - **Performance indicator:** quality of the global coverage by the different instruments of operational geostationary satellites.
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- 6.3.1.1. High-resolution multi-spectral visible/infra-red imagers.

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- Visible / infra-red imagers are currently available on all the geostationary satellites. The number of channels and the imagery resolution are variable from one satellite to the other. The GEO imagers are used in several applications, primarily for nowcasting and VSRF. They are very useful for detecting dangerous weather phenomena and for monitoring their rapid development and motion. They observe the clouds (amount, type, temperature of the top). From tracking clouds and water vapour features on image time series, wind observations are derived: atmospheric motion vectors (AMVs). Surface temperature is derived over sea and over land, as well as atmospheric stability indices. The GEO imagery is also used to detect precipitation, aerosols, snow cover, vegetation cover, fires and volcanic ash.

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[51] See: http://www.wmo.int/pages/prog/gcos/aopcXVI/8.9_RecognitionDatasets.pdf

- By 2025, an increased space/time resolution is expected for most of the GEO satellite imagers, and it is important to improve the data collection and the data exchange accordingly.

Action S4

- **Action**: On each operational geostationary satellite, implement and maintain at least one visible / infra-red imager with at least 16 channels providing full disk coverage, with a temporal resolution of at least 15 minutes and a horizontal resolution of at least 2km (at sub-satellite point).
- **Who**: CGMS leading the action, with WMO commissions and satellite agencies.
- **Time-frame**: Continuous.
- **Performance indicator**: number of geostationary satellites equipped with high resolution imagers.

Action S5

- **Action**: For each geostationary satellite, organize the scanning strategy and the processing of the imagery (together with other instruments or other sources of information) in order to produce AMV with at least a 1h frequency.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres..
- **Time-frame**: Continuous.
- **Performance indicator**: number of geostationary satellites producing AMVs operationally.

6.3.1.2. Hyper-spectral infra-red sounders

- Infra-red sounders have been used for a long time on LEO satellites. Hyper-spectral infra-red sounders are now operational on some LEO satellites (e.g.: IASI on the Metop satellite) but not on GEO. Some years ago, CGMS endorsed the concept of the International Geostationary Laboratory (IGeoLab) which is a joint undertaking to provide a platform for demonstrations from geostationary orbits of new sensors and new capabilities. The evaluation of the potential of hyper-spectral sounders on GEO has been one of the IGeoLab projects; it was also performed with the GIFTS mission which was considered by the USA.

- Several operators of geostationary satellites have firm plans to include hyper-spectral infra-red sounders for the next series of satellites. Detailed plans for the different series of GEO satellites are given in the Dossier (section on "Programmes" - see footnote 49 in section 6.1 of this report).

- These planned sounders put the emphasis on high horizontal resolution (better than 10km), and on high vertical resolution (about 1km). Their main objective is to provide frequent information on the 3D structure of atmospheric temperature and humidity, for the whole Earth disk seen by the satellite (except in and below clouds). They will be used, together with the imagers, to produce high resolution winds (AMVs from clouds or water vapour features), to track rapidly evolving phenomena, and to determine surface temperature (sea and land). They are also designed to have an important role in the frequent observation of atmospheric chemical composition.

Action S6

- **Action**: All meteorological geostationary satellites should be equipped with hyper-spectral infra-red sensors for frequent temperature and humidity soundings, as well as tracer wind profiling with adequately high resolution (horizontal, vertical, time).
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres..
- **Time-frame**: Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.
- **Performance indicator**: number of geostationary satellites equipped with hyper-spectral sounders.

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- 6.3.1.3. Lightning imagers

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- A lightning imaging satellite mission has no heritage from any current or past geostationary mission. It is intended to provide a real-time lightning detection and location (with an accuracy of 5 to 10km) capability, primarily in support to nowcasting and VSRF. It is designed to detect cloud-to-cloud and cloud-to-ground strokes with no discrimination between the two types.

-

- As lightning is strongly correlated with storms and heavy precipitation, another objective of a lightning mission is to serve as proxy for intense convection and convective rainfalls. It could serve as proxy for diabatic and latent heating to be assimilated in NWP models. It will also help the generation of a complete lightning climatology, together with the surface-based lightning observing systems (see 5.3.2.4). Finally, lightning plays a significant role in generating nitrous oxides, and lightning observations could be an important source of information for atmospheric chemistry models.

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- A lightning imaging mission is planned before 2025 for most of the geostationary satellite programmes: the European MTG (LI: Lightning Imager), The American GOES, from GOES-R onwards (GLM: Geostationary Lightning Mapper), the Russian GOMS[52] and the Chinese FY-4[53].

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Action S7

- **Action**: All meteorological geostationary satellites should be equipped with a lightning imager able to detect cloud-to-cloud and cloud-to-ground strokes.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres..
- **Time-frame**: Continuous for the mission planning and preparation; 2015-2025 for making the instruments operational.
- **Performance indicator**: number of geostationary satellites equipped with a lightning imager.

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- 6.3.2. Operational polar-orbiting sun-synchronous satellites

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For achieving good global data coverage, the Vision-2025 envisages at least 3 operational polar orbiting satellites (with a minimum set of instruments) plus other satellites on various orbits. The Equatorial Crossing Time (ECT) of the 3 satellites is envisaged at 13:30, 17:30 and 21:30 (local time). The orbit ECT choice for the 3 operational satellites (and for all the other polar orbiting satellites) must be permanently monitored through an international cooperation.

Action S8

Action: Ensure the orbit coordination for all core meteorological missions in LEO orbit, in order to optimize temporal and spatial coverage, while maintaining some orbit redundancy. The LEO missions should include at least 3 operational sun-synchronous polar orbiting satellites with ECT equal to 13:30, 17:30 and 21:30 (local time).
Who: CGMS leading the action, with WMO technical commissions and space agencies.
Time-scale: Continuous.
Performance indicators: number and orbit distribution of contributing LEO satellite missions.

- These orbiting platforms (with ECT equal to 13:30, 17:30 and 21:30) should be equipped with at least an hyper-spectral infra-red sounder, a microwave sounder and a high resolution multi-spectral visible / infra-red imager.

-

[52] Geostationary Operational Meteorological Satellite
[53] FengYun 4 Meteorological Satellite

- Compared with geostationary satellites, it is more difficult with polar platforms to implement a rapid data collection (from the platform to the ground segment), and then for the data delivery to meet the timeliness requirements of the several user applications.

Action S9

- **Action**: Improve timeliness of LEO satellite data, especially of the core meteorological missions on the three orbital planes, by developing communication and processing systems which achieve delivery in less than 30 minutes (as done with the RARS network for some data sets).
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: timeliness of LEO satellite data, as judged by the usual monitoring scores.

Action S10

- **Action**: Improve local access in real-time to LEO satellite data, especially to the core meteorological missions on the three orbital planes, by maintaining and developing direct read-out communication and processing systems.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: volumes of LEO satellite data accessible by direct read-out.

6.3.2.1. Hyper-spectral infra-red sounders.

- The current (2012) experience on hyper-spectral sounders is based on the use of IASI on the Metop[54] satellite, and of AIRS on AQUA[55]. Compared to the previous infra-red sounders, they provide much more details in the vertical on the temperature and humidity structure. Their main drawback is that they are limited to sample the clear-sky atmosphere and the portion which is above the clouds. But they are also a significant source of information for sea/land surface temperature, atmospheric composition and cloud variables. Impact studies have shown that they have a strong positive impact on global NWP. They are also expected to have an important role for complementing microwave instruments in the preparation of climate data records (see next section 6.3.2.2 on microwave sounders).

- One difficulty for the users of hyper-spectral infra-red sounders is the huge volume of redundant data to process. Each user is interested in the information from a specific subset of this huge volume, and this subset varies from one application to another. For example, global NWP is interested in a representation of the data that gives most information on the temperature and humidity profiles, whilst the atmospheric composition community is interested in information on specific atmospheric constituents. It is a challenge for the centres pre-processing these observations to provide a satisfactory data delivery to all users in an operational context."

Action S11

- **Action**: Design the ground segments for hyper-spectral infra-red sounders in order to define and implement a data reduction strategy which optimizes the information content accessible within the timeliness and cost constraints, whilst addressing the needs of different user communities.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.

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[54] EUMETSAT Polar Orbiting Operational Meteorological Satellite
[55] http://aqua.nasa.gov/

- **Performance indicator**: volume and timeliness of the different data sets distributed to the users of hyper-spectral sounders.

6.3.2.2. Microwave sounders

Microwave sounders have been used in meteorology since the decade 1970-1980, mainly from the American NOAA series of satellites, equipped first with the Microwave Sounding Unit (MSU), then with the Advanced Microwave Sounding Unit (AMSU). They provide information on the atmospheric vertical profiles of temperature and humidity, but with a coarser vertical resolution compared to hyper-spectral infra-red sensors. Their main advantage on infra-red sounders is their capacity to observe in and below the clouds. Currently (2012), they are available for meteorological operations on several satellites (5), and they provide a backbone for large-scale global assimilation systems. NWP impact studies have shown that these observations provide a very strong positive contribution.

In addition to their key role for the observation of atmospheric temperature and humidity, microwave sounders provide information on cloud water content and precipitation.

Specific microwave radiance data from satellites, especially from the MSU and AMSU instruments, have become key elements of the historical climate record, and they need to be continued in the future to sustain a long-term record. A GCOS-IP action aims at ensuring the continued derivation of microwave radiance data for climate data records. This climate recommendation is reinforced by the key role taken by the microwave sounders in global re-analyses.

Action S12

- **Action**: Fill the gap in planned coverage of microwave sounders in the early morning orbit.
- **Who**: CGMS leading the action, with WMO commissions and satellite agencies.
- **Time-frame**: Continuous.
- **Performance indicator**: number of microwave sounders planned for satellites in early morning orbit.

6.3.2.3. High resolution multi-spectral visible/infra-red imagers

Visible / infra-red imagers have been used since the beginning of satellite meteorology in the decade 1960-1970. At this time they provided very useful qualitative information for meteorologists, especially on the type and position of clouds and weather systems. Since then, a lot of technological progress has been performed on imagers, particularly on their horizontal resolutions and on the number of channels. Imagers on LEO satellites complement very well those on GEOs, by observing the middle and high latitudes, although their observation frequency is limited by their orbit configurations.

The observational capabilities of imagers onboard LEO satellites are very similar to those on geostationary satellites (clouds, surface temperature, snow and ice cover, etc. - see 6.3.1.1). They are most useful for nowcasting and VSRF in the polar areas. They can also be exploited for producing AMVs (cloud-tracked winds or water-vapour-tracked winds). MODIS[56] winds have been used in operational NWP for several years, and a very significant positive impact has been demonstrated, probably due to the lack of other types of upper-air wind observations over the polar caps.

Comment [ajs53]: Could also mention their use for surface conditions and for providing aerosol data..

Action S13

[56] MODIS: MODerate-resolution Imaging Spectrometer (onboard AQUA and TERRA satellites).

- **Action**: Use the imagers of all operational polar orbiting platforms to produce AMVs from the tracking of clouds (or water vapour features)
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Volume and timeliness of the different data sets produced operationally on the polar caps.
-

Action S14

- **Action**: Implement a water vapour channel (e.g. 6.7 μm) on the imager of all core meteorological polar-orbiting satellites to facilitate the derivation of polar winds from water vapour motion.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Number of core meteorological polar-orbiting satellites with a water vapour channel in its imager.
-
-

- 6.3.2.4. Microwave imagers

-
- The microwave imagers are similar to the passive microwave sounders discussed in 6.3.2.2, except they have different characteristics in wavelengths and spatial resolution which make them more appropriate for the observation of the land or sea surface. Over the oceans they provide information on sea-ice, surface wind speed and sea surface temperature. Over land they observe surface temperature, soil moisture and snow water equivalent. They also provide information on the precipitation and total column atmospheric water vapour. Polarimetric imagers also provide information on sea surface wind direction.
-
- Since the decade 1990-2000, the total column water vapour and the surface wind speed information provided by the Special Sensor Microwave Imager (SSM-I) instrument onboard the American satellites DMSP[57] have been used widely for weather and climate applications. Initially the use of the data was limited to the ocean, but more recently a lot of progress has been achieved on the use of microwave satellite information over land. The role of these microwave sensors is also important for monitoring the sea ice limits around the polar caps. Thanks to the continuity of the DMSP/SSM-I observations during the last 20 years, these sensors make important contributions both to climate monitoring and to global re-analyses.

Comment [ajs54]: This is a bit too kind. Transition to SSMIS has been problematical.

-
- To meet the different user requirements, at least 3 satellites with microwave imagers are needed on well separated orbits. According to current plans the requirements are expected to be met.
-
-

- 6.3.3. Additional operational missions in appropriate orbits

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- In addition to the imagers and sounders listed above and operated on GEO and LEO orbits, several other satellite instruments are used for weather, ocean, climate and other applications. Many of them (but not all) are operated on polar orbiting sun-synchronous satellites. Several instruments serve the needs of more than one application.
-

- 6.3.3.1. Scatterometers

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[57] DMSP: Defence Ministery Satellite Programme (from the USA): among the different instruments onboard DMSP satellites, the SSM-I is the Special Sensor Microwave Instrument (used in operational meteorology).

- Unlike microwave imagers which are passive instruments, scatterometers onboard satellites are an active observing system. Scatterometers provide information mainly on the oceanic surfaces (sea surface wind speed, ice cover) and also for the land surface (soil moisture).
-
- The first scatterometer data to be assimilated in operational global NWP models were the oceanic wind observations of the European ERS-1[58] satellite in the decade 1990-2000. Since then, scatterometers have been provided to NWP and other applications, from satellites like ERS-2, QuikScat[59], Metop (and its ASCAT[60] instrument) - see the Dossier for a list of instruments and missions. They generally provide a very good global data coverage (with some limitations on the maximum wind speed, or over sea ice) which helps considerably to meet the meteorological and oceanic requirements in terms of surface wind. Over land the use of scatterometer data is not as mature, but a lot of progress has recently been achieved on the use of soil moisture information.
-
- At least two satellites flying on well-separated orbits with a scatterometer onboard are needed and should be maintained in the future. According to the present plans the requirements are expected to be met.
-
-

Comment [ajs55]: Why do we say "At least two" for scatterometers where earlier we say "three" for microwave imagers?

- 6.3.3.2. Radio-occultation constellation

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- The use of radio-occultation in meteorology is a good example of observing systems based on an opportunity: (i) the continuous availability of GNSS radio signals emitted by about 30 GNSS satellites (probably around 60 in 2015-2025), orbiting at an altitude of about 22000 km; (ii) the perturbing role of the atmosphere which slows down the signal propagation, and generates atmospheric refraction. Then, by installing GNSS receivers on other satellites (ad hoc constellation or operational meteorological satellites, generally in LEO), it becomes possible to measure the delays of the signals due to their propagation through the atmosphere. These delays are mainly dependent on the air density, and they provide useful information on temperature, especially in the stratosphere and upper troposphere, and on humidity in the lower troposphere.
-
- Radio-occultation measurements have been assimilated in operational NWP models since about 2005 from several satellites: CHAMP[61], GRACE-A[62], Metop (with its GRAS[63] instrument), the COSMIC constellation[64] (see Poli et al., 2009). Their impact on the analyses and forecasts has been evaluated by several NWP centres, and the main results have been discussed in the 4th WMO workshop on impact studies (see footnote 20, section 4). Taking into account the very indirect character of the observing system through instruments which were not primarily designed for meteorology, this positive impact has been found surprisingly large. In addition, the data coverage obtained from a constellation of receiving satellites is global and quite uniform. The system offers absolute measurements (self-calibrated), not contaminated by clouds, which is a big advantage with respect to (i) the general inter-calibration of satellite data; (ii) the creation of climate data records.
-
- Most of the existing satellites currently providing radio-occultation measurements to operational applications are not operational satellites and do not belong to any satellite programme whose future continuity is guaranteed. For the period 2012-2025, it is important to plan the continuity of a sufficient number of receiving satellites, to avoid losing the benefits of the important investments made on the production of radio-occultation measurements and on their use in operational meteorology.
-

Action S15

[58] ERS = Earth ressource Satellite; ESA mission (ERS-1 started in 1991 and was followed by ERS-2)
[59] Quick Scatterometer (NASA)
[60] Metop's Advanced SCATterometer
[61] CHAllenging Minisatellite Payload
[62] GRACE: Gravity Recovery And Climate Experiment
[63] GNSS Receiver for Atmospheric Sounding
[64] http://www.cosmic.ucar.edu/

- **Action**: Ensure and maintain a radio-occultation constellation of at least 8 GNSS receivers onboard 8 platforms on different orbits, and organize the real-time delivery to processing centres.
- **Who**: CGMS to lead the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Number of satellites providing GNSS signals in real-time.
-

Action S16

Action: Perform an Observing System Simulation Experiment (OSSE) to evaluate the impact of different numbers of platforms in a GNSS constellation, and to estimate the optimal number of platforms required.

Who: NWP centres, in coordination with CBS/ET-EGOS (to lead the action) and CAS/THORPEX.

Time-scale: Before 2013 (end of THORPEX).

Performance indicators: A number of OSSEs carried out.

- Another application of the GNSS signals and radio-occultation is the measurement of electron density in the ionosphere. Therefore the future radio-occultation constellations will contribute also to the space weather applications (see section 6.3.5).

-

6.3.3.3. Altimeter constellation

-

- SSH is one of the key variables to observe for ocean analysis and forecasting and for coupled ocean-atmosphere modelling. SSH has been observed through a series of satellite altimeters since the beginning of the decade 1990-2000: ERS-1 and 2, JASON-1[65] and 2, ENVISAT[66], GEOSAT[67], etc. - see the WMO “Dossier”, footnote 49 in 6.1, for documentation on these satellites and their instrument characteristics. Satellite altimeters provide measurements of the ocean topography and of the significant wave height with a global coverage and a good accuracy. The surface wind can also be estimated from the wave observation. However the horizontal and temporal resolutions are limited by the instrument producing observations only at the nadir of the satellite (for most instruments). The horizontal resolution can be good along the satellite track, and the main limitation is “across-track” in mid-latitudes: there is generally a 300km gap between measurements from two consecutive orbits.

-

- Several altimeters are also able to provide measurements on ice topography (over sea and land) and on the lake levels (applications to glacier monitoring and hydrology). Unfortunately, there is a gap in laser altimetry between NASA’s first and second ICESat satellites. While the radar altimeter on Cryosat-2 is also for sea and land ice measurements, the ideal altimeter constellation would have both laser and radar altimeters. The combination would provide greater accuracy in sea ice thickness estimates, and might provide information on the depth of snow on the ice.

-

- In the future, several altimeter instruments (planned or already flying) will continue to support these applications: ALT on HY-2A[68], AltiKa[69] on SARAL[70] - see WMO Dossier, footnote 49 in section 6.1 for details. In the period 1990-2010, the number of operational altimeters has varied from 1 to 4. It is generally agreed that a minimum of two satellites on sun-synchronous orbits, plus one reference mission, will be necessary to meet the requirements of operational oceanography.

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Action S17

- **Action**: Implement an altimeter constellation comprising a reference mission on high-precision, not sun-synchronous, inclined orbit, and two instruments on well separated sun-synchronous orbits.

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[65] Ocean Surface Topography mission (USA/France)
[66] ESA Environmental Satellite mission
[67] GEOdetic SATellite
[68] HaiYang ocean satellite mission (China)
[69] High accurate oceanography altimeter
[70] Environment monitoring mission (India/France)

- **Who**: CGMS leading the action, with WMO commissions, JCOMM, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Number and orbit geometry of satellites providing altimetry in real-time.
-
-

6.3.3.4. Infra-red dual-angle view imager

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- For climate monitoring purposes it is important to have continuous records of very accurate measurements of SST. In the GCOS-IP an action states: "Continue the provision of best possible SST fields based on a continuous coverage-mix of polar orbiting and geostationary infra-red measurements, combined with passive microwave coverage and appropriate in-situ networks". To achieve the required quality of SST fields it is important to have at least one infra-red instrument with a dual view for accurate atmospheric corrections. Such instruments have already been used: ATSR[71] on ERS, AATSR[72] on ENVISAT - see WMO Dossier, referenced by footnote 49 in 6.1, chapter "Instruments". Another one is planned for the Sentinel 3 mission: the SLSTR (Sea and Land Surface Temperature Radiometer).
-

Action S18

- **Action**: Ensure and maintain in operations at least one infra-red dual-angle view imager onboard a polar orbiting satellite in order to provide SST measurements of climate monitoring quality.
- **Who**: CGMS leading the action, with WMO commissions, JCOMM, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Operational availability of dual-angle view imagers.
-

- The high-quality SST fields obtained through these infra-red imagers will also be useful for applications other than climate monitoring, in operational meteorology and oceanography. Also these imagers will contribute to the observation of aerosols and clouds.

Comment [ajs56]: Could include fires here. FRP observations are needed operationally - we get them from MODIS and the GEOs.

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6.3.3.5. Narrow-band high-spectral and hyper-spectral visible /near infra-red imagers

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- Remote-sensed observations of the ocean colour are useful for detecting several types of marine pollution, they can provide images of biological variables of the marine life with a high horizontal resolution (a few hundred metres). Observations of ocean colour are required for several marine applications and for the validation of ocean models.
-
- The observations of ocean colour require passive imagers with narrow bands in the visible and near-infra-red spectrum. Several instruments of this type have already been operated, like the COCTS[73] on the Chinese HY-satellite series, the GOCI[74] on the Korean COMS[75] satellite, the MERIS[76] on the European ENVISAT satellite, or the OCM on the ISRO Oceansat-1 and Oceansat-2 satellites. For the future, other instruments are planned, like the OCS[77], or the OLCI[78] on the Sentinel-3[79].
-

[71] Along Track Scanning Radiometer
[72] Advanced Along-Track Scanning Radiometer
[73] Chinese Ocean Colour and Temperature Scanner
[74] Geostationary Ocean Colour Imager
[75] Communication, Ocean and Meteorological Satellite
[76] MEd Resolution Imaging Spectrometer
[77] Ocean Colour Scanner on the Russian Meteor Satellite
[78] Ocean Land Colour Imager
[79] A multi-instrument ESA satellite mission contributing to the Global Monitoring for Environment and Security (GMES)

- The narrow-band imagers operated in the visible and near-infra-red are also useful for observing the vegetation (including the monitoring of burnt areas), the surface albedo, the aerosols and the clouds.

-

This narrow-band mission is currently well covered by LEO satellites.

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- 6.3.3.6. High-resolution multi-spectral visible / infra-red imagers

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- For vegetation classification, land use monitoring and flood monitoring, visible / infra-red imagers are needed with characteristics emphasizing high horizontal resolution. These high-resolution instruments are normally applicable only on LEO satellites. The Leaf Area Index (LAI) is one of the main variables sought for agrometeorology from satellite data for use in crop simulation models. Although the LAI can be retrieved from several imagers, the highest resolution is achieved through the instruments of the LANDSAT[80] and SPOT[81] series. The land surface is observed with a horizontal resolution of dam order of magnitude. With instruments like the CHRIS onboard PROBA-2[82], the resolution can reach 2.5m on some specific targeted areas.

-

- It is essential to continue this type of satellite mission in the future on order to guarantee the continuity of the existing series. This is important for agrometeorology, hydrology, land use, careful monitoring of disasters (floods, fires) and the very high-resolution imagers will have several other specific utilizations.

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- 6.3.3.7. Precipitation radars with passive microwave imagers

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- Estimating the global field of precipitation amount (with precipitation type) at different time-scales is one of the more challenging tasks in weather and climate applications. One reason is related to the high variability in space and time of precipitation: in convective situations, flooding rains may affect one area with no precipitation at all a few kilometres away; the accumulated rainfalls (on 1h, 1 day, 1 month or 1 year) varies by one or two orders of magnitude between the equator and the poles, and precipitation is almost non-existent in tropical and sub-tropical deserts. A second reason is that there is no hope to obtain a global coverage of precipitation observation through surface-based raingauges and radars: in spite of the efforts made for expanding and improving the surface-based radar networks (see section 5.3.4.), the coverage will always be limited. However a proper estimation of precipitation fields is essential at all time-scales, from those required by the climate monitoring (several years, globally) to the local estimate of rainfall accumulated on 1h or less (flood monitoring). An ad hoc space-based precipitation observing system is very important to achieve this goal.

Comment [ajs57]: Rather a statement of the obvious as currently worded, so would benefit from a rewrite.

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- The concept of Global Precipitation Measurement (GPM) missions combines active precipitation measurements (made from space-based radars) with a constellation of passive microwave imagers (discussed in 6.3.2.4). The GPM constellation is planned to include a core mission with a 65° inclination orbit (with respect to the equator), plus several satellites developed by several national or international agencies. Its objective is to provide a global coverage of precipitation data at 3h intervals, and 8 satellites are needed to achieve this objective. The satellites will be equipped with active precipitation radars, or passive microwave instruments, or generally both. The characteristics of the existing and planned radars can be found on the WMO Dossier (footnote 49, section 6.1): search for example the CPR (Cloud and Precipitation Radar) or the DPR (Dual-frequency Precipitation Radar) in the instrument chapter of the Dossier.

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[80] Earth-observing satellite mission (NASA/USGS)

[81] Satellite Pour l'Observation de la Terre

[82] CHRIS = Compact High Resolution Imaging Spectrometer, onboard the PROBA-2 (PRoject for OnBoard Autonomy) satellite. PROBA-2 (after PROBA) is a demonstration mission of ESA, which has more and more routine users.

- This type of measurement has already proven its value, first on the TRMM[83] mission (satellite launched in 1997), and on the CLOUDSAT[84] mission, launched in 2006 by the USA, as part of the "A -Train"[85], to monitor the water cycle of the Earth, and also clouds and aerosols. The MEGHA-Tropiques Mission (MTM[86]), prepared through a collaboration between France and India, launched in 2011, also contributes to this project whose emphasis is put on precipitation and water cycle. Several satellites (planned or already flying) will have a low orbital inclination from the equator. For example, the MTM satellite flies between 20S and 20N. In this way, they will provide more frequent data near the equator, compared to the usual polar orbiting satellites whose inclination is close to 90°. This is important for a better understanding and modelling of the diurnal cycle in the tropics. The data availability in real-time is also important for nowcasting and operational hydrology.

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Action S19

- **Action**: In support of GPM, implement at least one passive MW mission on a low-inclination orbit
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Availability of one passive MW satellite mission on a low-inclination orbit.
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Action S20

- **Action**: Organize the delivery of GPM data in real time to support nowcasting and operational hydrology requirements.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Extent to which availability requirements for nowcasting and operational hydrology are met by the GPM mission.

Comment [ajs58]: This is a bit weak and here-and-now. Should the need for sustaining a GPM-type activity to 2025 and beyond be mentioned here.

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- 6.3.3.8. Broad-band visible/infra-red radiometers for Earth radiation budget

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- The Earth Radiation Budget (ERB) measures the overall balance between the incoming energy from the sun and the outgoing thermal (long-wave) and reflected (short-wave) energy from the Earth. It can only be measured from space, thus the continuity of observations is an essential issue for climate applications (see GCOS-IP, section about ERB).

-

- In addition to imagers and sounders on LEO and GEO satellites, and to aerosols and cloud properties measurements (see sections above from 6.3.2), the ERB requires at least one polar orbiting satellite equipped with a broad-band visible / infra-red radiometer and a sensor for measuring the total solar irradiance.

-

- Broad-band radiometers were available in the past on the ERB Satellite (ERBS) and are available on the TERRA and AQUA satellites. The SCARAB[87] instrument flying on MTM also contributes to the ERB.

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Action S21

- **Action**: Ensure the continuity of ERB type global measurements by maintaining operational broad-band radiometers and solar irradiance sensors on at least one LEO polar orbiting satellite.

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83 Tropical Rainfall Measuring Mission
84 NASA EOS mission to observe clouds
85 The A-Train includes several satellites flying in formation: AQUA, AURA, CLOUDSAT, CALIPSO, PARASOL (The OCO launch failed in February 2009)
86 CNES/ISRO Megha-Tropiques Mission to observe the water cycle and energy budget in the tropics
87 Scanning radiative budget instrument

- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Number of polar orbiting satellites contributing to the ERB.

6.3.3.9. Atmospheric composition instrument constellation

As mentioned above (5.3.1.4), a number of atmospheric constituents have an important role in climate forcings and feedbacks. This is the case for ozone, methane, CO_2 and others. Details can be found in the GCOS-IP. Several of these constituents will become important variables of NWP-ACM models (or already are, like ozone). The observations of these variables should become fully integrated in the WIGOS and then exchanged in real-time to meet the requirements of atmospheric chemistry applications, including air quality monitoring, and NWP.

Since the decade 1980-90 several above-mentioned sounders (like infra-red sounders) have contributed to the measurements of atmospheric ozone, aerosols and some other gases. In addition, several demonstration satellite missions or instruments have been devoted to atmospheric chemistry, like the Japanese GOSAT[88], specifically addressing the observation of key Green-House Gas (GHG) for climate change, with thermal and near-infra-red instruments onboard . Other examples of instruments devoted to atmospheric chemistry are:

- TOMS and SBUV onboard NOAA and other satellites, POAM[89] onboard SPOT satellites (limb solar occultation sounder for ozone, aerosols and other constituents).
- GOME[90] onboard ERS-2, GOMOS[91] and SCIAMACHY[92] onboard ENVISAT.
- GOME-2 on Metop.

For the future, the OMPS[93] is planned for some American operational satellites. It will add to the nadir measurements the limb sounding for high vertical resolution in the stratosphere. It will measure ozone, but also NO_2, SO_2 and a few other constituents. In the European programme GMES[94], the platforms called Sentinel-4 (GEO, MTG) and Sentinel-5 (LEO, EPS-SG) should carry ultra-violet, visible and near-infra-red sounders for supporting atmospheric chemistry. See the WMO Dossier (footnote 49) for more details.

Comment [ajs59]: I'm not sure OMPS gives us enough limb sounding. Will NPP last until after JPSS2 is launched? Where are the long-term plans for limb sounding?

Action S22

- **Action**: For atmospheric chemistry, monitoring of green-house gas and of air pollution, ensure the operational continuity of some ultra-violet / visible / near-infra-red sounders, including high spectral resolution ultra-violet sounders on GEO, and at least one ultra-violet sounder on 3 well-separated polar orbits. Ensure also the continuity of limb-sounding capability.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies and data processing centres.
- **Time-frame**: Continuous.
- **Performance indicator**: Number of GEO and LEO ultra-violet / visible / infra-red sounders contributing to atmospheric chemistry.

Comment [ajs60]: CGMS seems to lead everything here. What about CEOS? The word "constellation" appears in the title of this section.

For more details about the operational continuity of some atmospheric composition sounders , see GCOS-IP, section dealing with atmospheric chemistry.

6.3.3.10. Synthetic Aperture Radar (SAR)

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88 GOSAT: Green-house gaz Observing Satellite, launched in January 2009.
89 POAM: Polar Ozone and Aerosol Measurement
90 GOME: Global Ozone Monitoring Experiment
91 GOMOS: Global Ozone Monitoring by Occultation of Stars
92 SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmosphere Chartography
93 OMPS: Ozone Mapping and Profiler Suite
94 GMES: Global Monitoring for Environment and Security

-

- Compared with a normal radar, the SAR processes the series of images in a special way, in order to increase considerably the spatial resolution locally, which implies some trade-offs on other geometrical variables of the radar measuring technique: scanning angle, swath size, etc. With SAR observing systems onboard LEO satellites, one can obtain locally very high resolution observations of land surface, wave heights (and directions plus spectrum), sea level (especially near the coasts), water level in flooded areas, sea ice caps, ice sheets and icebergs.

-

- The SAR technology has been used on several satellites: ERS-1, ERS-2, ENVISAT (with its Advanced Synthetic Aperture Radar (ASAR) instrument), ALOS[95] (JAXA[96] satellite with its PALSAR[97] instrument). The ESA satellite CRYOSAT-2[98] has been launched in 2010 with its SAR instrument called SIRAL[99]. These SAR instruments have been used for both research and operational applications. For the future, several SAR missions are planned as well; for example the planning and development of the SAR-C instrument (radar in C band) on the GMES Sentinel-1 mission is a very good step towards integration of the SAR observing system into the operational observing systems. The future Radarsat Constellation Mission (RCM) planned for 2015-2023 will include 3 satellites phased on the same orbit, enabling a 4-day revisit time.

Comment [ajs61]: Provided there is a proper operational budget for GMES

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- It is not feasible to obtain in real-time a global coverage of SAR data. In addition the SAR processing delays are important, which often prevents a rapid delivery. However it is important to have at least one operational SAR satellite mission whose continuity is guaranteed, and integrated in the WIGOS, with proper mechanisms to ensure a rapid delivery of data at the regional and local scales, in order to cope efficiently with high-risk phenomena and disaster management. Because of the local character of the SAR-targeted areas and of the high volume of data to process, it is actually desirable to have more than one satellite mission complying with these operational characteristics.

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- 6.3.4. Operational pathfinders and technology demonstrators

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- It is important to pursue investigations on some new satellite instruments and some new space technologies even if the final operational success is not guaranteed, provided these new systems are expected to help significantly for meeting the user requirements. In the past, several research or demonstration missions produced a beneficial operational outcome much more quickly than expected originally by the potential users. Several pathfinders and technology demonstrators are discussed below. They are all challenging but achievable by 2025, with a good chance to be an operational part of global observing systems by 2025 for some of them, and a reduced chance for some other systems.

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- 6.3.4.1. Lidars on LEO satellites

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- Lidar instruments flying on satellites have been used in meteorology or are planned to be used as demonstration satellite missions. The lidar can be designed to observe some of the following atmospheric components: profiles of wind components (from Doppler shifts), aerosols, cloud-top and cloud-base height, water vapour profile. Space-borne lidars are also used in altimetry (see 6.3.3.3).

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- **a) Doppler wind lidars**

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[95] Advanced land observing Satellite "Daichi"
[96] Japan Aerospace Exploration Agency
[97] Phased Array L-band Synthetic Aperture Radar
[98] ESA ice mission
[99] Synthetic Aperture Interferometric Radar Altimeter

- Space-borne Doppler wind lidars are the best hope for filling a big gap in the global data coverage: the lack of wind profile measurements which are currently too dependent on a single observing system, the radiosonde network.
-
- An ESA demonstration mission, ADM-AEOLUS, is planned from 2013 to 2015 to test wind profile measurements made from the ultra-violet lidar, ALADIN[100]. ADM-AEOLUS[101] will be operated from a polar orbiting satellite and will provide global observations of wind profiles. It is very important to have these data delivered in real-time to the main NWP centres to check rapidly (the estimated life-time of ADM-AEOLUS is only 3 years) to what extent they can improve weather forecasts.
-
- Following a successful demonstration mission, it will become a priority to plan and design an operational system based on wind lidars, using the experience accumulated in the demonstration mission, to decide on the appropriate number of satellites and the instrument characteristics.
-

Action S23

- **Action**: Use the experience of demonstration missions (like the ADM-AEOLUS one) to plan and design an operational observing system based on Doppler wind measurements (providing a global coverage of wind profiles).
- **Who**: CGMS leading the action, with WMO commissions, ESA and other satellite agencies, data processing and NWP centres.
- **Time-frame**: As soon as possible after data have been provided by demonstration missions.
- **Performance indicator**: Number and quality of Doppler wind lidar profiles (made from space) available to the users.
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- **b) Cloud and aerosol lidars**
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- Cloud and aerosol lidar systems can provide accurate measurements of cloud top height and can also observe cloud base height in some cases (e.g.: stratocumulus). They are also able to provide an accurate observation of aerosol layers in the atmosphere.
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- The CALIOP[102] instrument has been available on CALIPSO since 2006, and the ATLID[103] instrument should fly on the EARTH-CARE[104] mission prepared by ESA and Japan, and planned for 2013[105]. Given the potential of these lidars, the data should be delivered for evaluation in operational centres (mainly forecasting and atmospheric chemistry applications). For the design of a possible operational system based on cloud/aerosol lidar, it is important to note that a Doppler wind lidar like the ADM-AEOLUS has also the capacity to observe clouds and aerosols, which raises the possibility of designing an operational system which would integrate wind, cloud and aerosol measurements.
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- For an efficient evaluation of the lidar data (as soon as the instrument is operated), it is important to have these data distributed in real-time, so that they can be be used (or at least evaluated) in operational numerical models dealing with atmospheric chemistry and weather forecasting.
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Action S24

- **Action**: Deliver cloud/aerosol lidar data produced from satellite missions to operational data processing centres and users. Use this experience to decide about a

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100 See http://www.esa.int/esaLP/LPadmaeolus.html; see also Stoffelen et al. (2005)
101 Earth Explorer Atmospheric Dynamics Mission
102 Cloud-Aerosol Lidar with Orthogonal Polarisation
103 ATmospheric LIDar
104 Earth Clouds, Aerosols and Radiation Explorer - see http://www.esa.int/esaLP/LPearthcare.html
105 For more details on CALIPSO, CALIOP, EARTH-CARE and ATLID, see the WMO Dossier (http://www.wmo.int/pages/prog/sat/Refdocuments.html#spacebasedgos)

possible cloud/aerosol operational mission (integrated or not with an operational Doppler wind lidar mission).

- **Who**: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, forecasting and atmospheric chemistry users).
- **Time-frame**: Continuous with a special effort phased with the EARTH-CARE mission.
- **Performance indicator**: Data volume produced by space-based cloud/aerosol lidars and used by operational applications.

c) Water vapour lidars

Feasibility studies have been carried out on the measurement of atmospheric water vapour profiles from lidars onboard LEO satellites. The objective has been found highly challenging, and no demonstration mission is currently planned for a water vapour lidar. It is still worth keeping a research activity on such an observing system, and worth planning a demonstration mission when appropriate.

6.3.4.2. Low-frequency microwave radiometer on LEO satellites

Microwave radiometers on LEO satellites have a capacity to observe ocean salinity and soil moisture, but with a limited horizontal resolution. At large scales, the salinity information will be useful in ocean applications, in seasonal and inter-annual forecasting and in climate monitoring. The soil moisture produced from these microwave instruments should also be useful in NWP, seasonal and inter-annual forecasting, hydrology and climate monitoring. The horizontal resolution provided by these instruments may be marginal for meeting the user requirements in the coastal areas and for high-resolution marine applications.

The SMOS[106] satellite was launched in January 2009 and is expected to provide data until 2014. The Argentinean / NASA mission[107] SAC-D is expected to provide similar data between 2012 and 2016. Such research data sets should be delivered to operational meteorological, hydrological and oceanographic centres for quasi real-time evaluation. If the benefits are judged sufficiently significant, an operational mission should be planned.

Comment [ajs62]: This reads as if it applies to SMOS, for which special arrangements were made for near real time delivery.

Action S25

- **Action**: Study the benefits brought by satellite demonstration missions like SMOS (missions based on low-frequency microwave radiometers) on atmospheric, hydrological and oceanic models, in a quasi operational context, and decide if a similar operational mission can be designed.
- **Who**: CGMS leading the action, with WMO commissions, JCOMM, satellite agencies, data processing centres, meteorological, hydrological and oceanic modelling centres.
- **Time-frame**: As soon as possible for impact studies, from 2013 onwards to decide on new missions.
- **Performance indicator**: improvement brought by using these microwave data on different models.

Ocean salinity and soil moisture are variables whose variations are important to consider at the climate scale. The archiving of data series is important; see recommendations in the ocean part of the GCOS-IP.

6.3.4.3. Microwave imagers / sounders on GEO satellites

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106 SMOS: Soil Moisture and Ocean Salinity; satellite demonstration mission led by ESA, see: http://www.esa.int/esaLP/ESAMBA2VMOC_LPsmos_0.html

107 See http://aquarius.nasa.gov/

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- Using microwave imagers and sounders from geostationary satellites could provide very frequent precipitation observations, together with cloud properties (liquid water and ice content), and atmospheric temperature / humidity profiles. However such instruments are highly challenging for several technical reasons. One reason is the need for very large antennas to be operated on GEO orbits.

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- The potential benefit of such satellite instruments would be very high in terms of global estimation of precipitation fields (at all time scales). They would be very good complements to the same type of instruments on LEO satellites (see sections 6.3.2.4 and 6.3.3.7 about microwave imagers, GPM and precipitation fields). Therefore there is a good case to plan a demonstration mission with microwave instruments onboard a geostationary satellite, as was considered by IgeoLab (see section 6.3.1.2) for infra-red sounders.

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Action S26

- **Action**: Plan and design a demonstration mission with microwave instruments onboard a geostationary satellite, aiming at a significant improvement in terms of real-time observation of clouds and precipitation.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, meteorological and hydrological modelling centres.
- **Time-frame**: As soon as possible, taking into account the maturity of technology.
- **Performance indicator**: Success of a microwave instrument onboard a GEO satellite, then improvement brought by the data to meteorological and hydrological forecasting.

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6.3.4.4. High-resolution, multi-spectral, narrow-band, visible / near-infra-red on GEO satellites

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- Such instruments on GEO satellites would be the natural complement of the visible / near-infra-red instruments onboard LEO satellites (presented in section 6.3.3.5). They would contribute to the observation of ocean colour, vegetation, clouds and aerosols, and they would help disaster monitoring, with the usual advantage of GEO versus LEO: the frequency of images which makes the observation almost continuous on the Earth disk seen by the satellite. However their implementation is much more challenging than on LEO because of the high altitude of the geostationary orbit.

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Action S27

- **Action**: Plan and design a demonstration mission with high-resolution visible / near-infra-red instruments onboard a geostationary satellite, aiming at improving significantly the observation of ocean colour, vegetation, clouds and aerosols with multi-spectral narrow-band sensors.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, meteorological, oceanic and environmental centres.
- **Time-frame**: As soon as possible, taking into account the maturity of technology.
- **Performance indicator**: Success of this type of instrument onboard a GEO satellite, then improvement brought by the data to meteorology, oceanography and environmental science.

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6.3.4.5. Visible / infra-red imagers on satellites in high inclination and Highly Elliptical Orbit (HEO)

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- The HEO has never been used in meteorology and oceanography. Its main advantage is that the satellite can stay close to the vertical of one particular region of the Earth (at high altitude) for several hours, and only a reduced time on the opposite side of the Earth. When the orbit inclination on the equator is high, it almost offers the observation continuity similar to that of a geostationary satellite but in a polar region. With visible / infra-red sensors onboard, a HEO satellite would offer an almost continuous observation of the large number of meteorological and oceanic variables normally observed by this type of sensors: clouds (and AMVs) at high latitudes, surface temperature, sea-ice, ash plumes, vegetation, fires and snow cover.

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Action S28

- **Action**: Plan and design a demonstration mission with visible / infra-red instruments onboard a HEO satellite with a highly elliptical orbit and a high inclination over the equator, in order to target a polar area). The aim is to obtain the same environmental observations with a quality similar to those obtained from GEO satellites.
- **Who**: CGMS leading the action, with WMO commissions, satellite agencies, data processing centres, meteorological and environmental centres.
- **Time-frame**: As soon as possible, taking into account the maturity of technology.
- **Performance indicator**: success of a visible / infra-red instrument onboard a HEO satellite, then improvement brought by the data to meteorology and environmental science.

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- 6.3.4.6. Gravimetric sensors

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- Satellites have been used for gravimetric measurements for several decades. Several gravimetric sensors are currently flying, like the USA GRACE[108] mission or the ESA GOCE[109] satellite.

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- Their instruments can measure the Earth gravity field and follow its variations in space and time. From these variations, one can detect information on the ground water mass, or on the mass of water in some lakes and rivers. Thus they contribute to the monitoring of the ground water, together with a set of in-situ observing systems described in 5.3.3.3.

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- Note that gravimetric instruments are often flying on multi-user platforms: for example GNSS receivers embarked on any gravimetry platform, if properly set up, can be used for radio-occultation of the atmosphere, contributing to forecasting and climate applications, as described in 6.3.3.2.

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6.3.5 Instruments for space weather on polar and geostationary platforms

Comment [j63]: This section should be revised, with a structure consistent with the rest of the document, and

Comment [j64]: This section should be revised, with a structure and content consistent, as far as possible, with the rest of the document, and using the latest input from SW experts.

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Space Weather Observation

Space Weather refers to physical processes, originating at the Sun and ultimately affecting human activities on Earth and in space. In addition to the continuous UV, Visible and Infrared radiation which provides radiative forcing to our weather and climate at the top of the atmosphere, the Sun emits energy in an eruptive mode, as flares of electromagnetic radiation (radio waves, infra-red, visible light, ultraviolet, X-rays), and energetic electrically charged particles through coronal mass ejections and plasma streams. The particles travel outwards as the solar wind, carrying parts of the Sun's magnetic field with them. The electromagnetic radiation travels at the speed of light and takes about 8 minutes to move from Sun to Earth, whereas the charged particles travel more slowly, taking from a few hours to several days to move from Sun to Earth. The radiation and particles interact with the Earth's magnetic field and outer atmosphere in complex ways, causing concentrations of energetic particles and electric currents in the magnetosphere and ionosphere. These can result in geomagnetic variations, aurora, and can affect a number of services and infrastructure on Earth, either at the surface, or airborne or space-borne.

Space weather observations are required: to estimate the occurrence probability of space weather disturbances; to drive hazard alerts when disturbance thresholds are crossed; maintain awareness of current environmental conditions; and to determine climatological conditions for the design of

[108] Gravity Recovery and Climate Experiment - http://www.csr.utexas.edu/grace/
[109] Gravity field and steady-state Ocean Circulation Explorer - http://www.esa.int/esaLP/LPgoce.html

both space based systems (i.e., satellites and astronaut safety procedures) and ground based systems (i.e., electric power grid protection and airline traffic management).

The vastness of space and the wide range of physical scales that control the dynamics of space weather demand that numerical models be employed to characterize the conditions in space and to predict the occurrence and consequence of disturbances. Data assimilation techniques must be utilized to obtain the maximum benefit from our sparse measurements. Space Weather observations are therefore used to drive empirical, physics-based, and data-assimilation models.

Forecasting the space environment conditions is enabled by monitoring the background magnetic configuration and precursor phenomenon that take place on the Sun and propagate in the interplanetary medium before reaching the Earth. This should be based, first of all, on the measurement of the solar electromagnetic output in order to detect eruptive or pre-eruptive structures on the solar disc, which requires measurements at visible, UV and X-ray. In addition, it involves the measurement of the plasma density, speed and magnetic field in the solar wind. The solar wind flows out from the solar surface and impacts the Earth geomagnetic field affecting the radiation environment, the ionosphere and the upper atmosphere.

A comprehensive space weather observation network shall include ground based and space-borne observatories. Both the ground based and the space based segments shall contain a combination of remote sensing and in-situ measurements.

Space Weather observation from the surface

Ground based sensors, play a key role to monitor the ionospheric and the geomagnetic environments.

Ionospheric monitoring is achieved by ground-based GNSS receivers, ionospheric scintillation receivers, ionosondes, riometers and scattering radars. Observations of the neutral wind are performed by ground based Fabry-Perot interferometers (FPIs).

Magnetospheric magnetic field observations are required globally with ground based magnetometers. Ground based geomagnetic monitoring also includes Auroral imaging by all-sky cameras.

The basic ground based observations for solar activity include solar imaging, including H-alpha images and the solar surface magnetic field with vector magnetographs. The solar radio emissions are observed with broad frequency radio spectrographs and radio imaging of the sun. The main limitation for ground based observations, however, is the filtering of the atmosphere for the solar electro-magnetic and particle radiation.

Space Weather observation from space

The solar wind measurements and most of the solar observations in X-ray and UV range can exclusively be performed from space. In particular, space-borne sensors will have to be used for observations of the solar radio wave spectra below ionospheric cut-off frequency. An essential instrument to determine the initial properties of Coronal Mass Ejections that erupt from the Sun and can strike Earth is the coronagraph. These faint, white-light images of the Sun must be obtained from space based sensors, and it is highly advantageous to have multiple coronagraph sensors located both in and away from the Earth-Sun line.

The first Lagrange point L1 is a unique vantage point for solar activity monitoring and interplanetary monitoring, the spacecraft remaining at a stable, intermediate distance between the Sun and the Earth. Provision should however be made for near real-time data acquisition on the ground through the use of at least 3 ground stations or data relay via geostationary or geo-transfer spacecraft. A spacecraft located at L1 can permanently monitor the sun and its corona, or acquire heliospheric imaging with sensors having wide angle visibility of the whole Sun-Earth line. Geostationary observatories also greatly contribute to solar imaging instruments,

Space based measurements of the ionosphere and of the geomagnetic field will enhance the ground-based measurement coverage to a planetary scale. Furthermore, detailed information on local spacecraft environment can best be obtained from observations aboard the spacecraft itself, especially of ionizing radiation and charged particles; the exception for this is the atmospheric drag, which can be deduced from ground based satellite tracking systems or from the data from onboard orbit determination instruments.

Radiative environment sensors have to cross the radiation belts to measure the trapped radiation. Spacecraft on a geotransfer orbit (GTO) can provide a comprehensive sampling of the environment. Scenarios combining sensors on GTO, polar orbiting spacecraft, geosynchronous orbits (GEO) and elliptical orbits should be considered for optimal spatial and temporal coverage taking into account the flight opportunities aboard Earth Observation satellites. All in-situ observations of the space radiation environment have to include spacecraft orbit information at the times of the data sampling.

Spaceborne sensors are also required for in-situ observations of the local magnetic field in space, at altitude ranges from LEO to GEO, and for the observations of the low frequency magnetospheric radio wave spectra. Spaceborne Auroral observations include sensors for auroral visible and UV imaging and auroral kilometric radiation.

Polar orbiting satellites can support ionospheric monitoring, and thermosphere neutral wind and density observations, which are used in combination with ground-based Fabry-Perot Interferometer (FPI) observations for global coverage. Sensor data about the microparticle flux as a function of size, velocity and angular distribution is also required from spaceborne sensors.

Current and future observing systems

The WIND, ACE and SOHO satellites are located near the Lagrangian L1 point, about 1.5 millions kilometres away on the Sun side of the Earth. They make direct in-situ measurements of the velocity, composition, magnetic field, density, oscillations and flux of the solar wind. These measurements could be relayed to Earth perhaps an hour before this wind hits the Earth's magnetopause (about 70000km above surface). This is therefore the maximum advanced warning of potentially damaging impacts on the Earth's environment.

Ground-based observations are, at present, mainly of the Sun itself. Plenty of other instruments make direct observations of the Sun's surface, from X-ray and UV imaging to measurements of its temperature, density, magnetic field and so on. Such observations of perturbations to the solar wind would have a lead time of about 3 days, but it is difficult to use directly for space weather predictions.

Geostationary and polar orbiting satellites also provide some information on the Sun's surface and on charged particles entering Earth's atmosphere, respectively.

The STEREO (Solar TErrestrial RElations Observatory, two satellites launched in 2006) pictures will provide full solar images, but in-situ measurements of fluxes (currently) directed away from Earth.

Comment [ajs65]: I don't understand this sentence.

Some of this information is currently used to make space weather predictions, and to inform space modelling efforts.

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ACRONYMS

3D	Three Dimensional
AATSR	Advanced Along-Track Scanning Radiometer
ACM	Atmospheric Chemistry Model
ADM-Aeolus	Earth Explorer Atmospheric Dynamics Mission
AIRS	Atmospheric Infrared Sounder
ALADIN	Atmospheric Laser Doppler Instrument
ALOS	Advanced land observing Satellite "Daichi"
Altika	High accurate oceanography altimeter onboard SARAL mission
AMDAR	Aircraft Meteorological Data Relay Programme
AMMA	African Monsoon Multidisciplinary Analyses
AMSU	Advanced Microwave Sounding Unit
AMV	Atmospheric Motion Vector
AQUA	Aqua satellite mission - http://aqua.nasa.gov/
Argo	International profiling float programme (not an acronym)
ASAP	Automated Shipboard Aerological Programme
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Metop's Advanced SCATterometer
ATLID	ATmospheric LIDar
ATOVS	Advanced TIROS Operational Vertical Sounder
ATSR	Along Track Scanning Radiometer
AWS	Automatic Weather Station
BUFR	FM 94 BUFR GTS format - Binary universal form for the representation of meteorological data
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarisation
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAS	WMO Commission for Atmospheric Sciences
CBS	WMO Commission for Basic Systems
CCD	Charge-Coupled Device
CCl	WMO Commission for Climatology
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CHAMP	CHAllenging Minisatellite Payload
CHRIS	Compact High Resolution Imaging Spectrometer
CHy	WMO Commission for Hydrology
CIMO	WMO Commission for Instruments and Methods of Observation
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLOUDSAT	NASA EOS mission to observe clouds
CNES	Centre National d'Etudes Spatiales (France)
COCTS	Chinese Ocean Colour and Temperature Scanner
COMS	Communication, Ocean and Meteorological Satellite (Rep. of Korea)
Concordiasi	An international project of the THORPEX-IPY cluster within the International Polar Year effort to provide validation data to improve the usage of polar-orbiting satellite data over Antarctica
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CPR	Cloud and Precipitation Radar
CREX	FM 95 CREX GTS format - Character form for the representation and exchange of data
CRYOSAT	ESA ice mission
DEMETER	Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions
DMSP	Defence Meteorological Satellite Program (USA)
EARS	EUMETSAT ATOVS Re-transmission Systems
EARTH-CARE	Earth Clouds, Aerosols and Radiation Explorer
E-ASAP	EUMETNET ASAP
EC	WMO Executive Council
ECT	Equatorial Crossing Time

- ECV Essential Climate Variable
- EGOS-IP Implementation Plan for the Evolution of Global Observing Systems
- ENVISAT ESA Environmental Satellite mission
- EOS NASA Earth Observing System
- EPS-SG EUMETSAT Polar System – Second Generation
- ERB Earth Radiation Budget
- ERBS The Earth Radiation Budget Satellite
- ERS Earth Resource Satellite (ESA)
- ESA European Space Agency
- ET-EGOS CBS Expert Team on the Evolution of Global Observing Systems
- EUCOS EUMETNET Composite Observing System
- EUMETNET Network of European Meteorological Services
- FAO Food and Agriculture Organization
- FDHSI Full Disk High Spectral resolution Imagery
- FLS fixed land station
- FY-4 FengYun 4 Meteorological Satellite (China)
- GAW Global Atmosphere Watch Programme
- GCMP GCOS Climate Monitoring Principles
- GCOS Global Climate Observing System
- GCOS-IP Implementation Plan for the Global Climate Observing System
- GDRC Global Runoff Data Centre
- GEO Geosynchronous satellite
- GEO Group on Earth Observations
- GEOS Geostationary Operational Environmental Satellite (USA)
- GEOSAT GEOdetic SATellite
- GEOSS Global Earth Observing System of Systems
- GFCS Global Framework for Climate Services
- GHG Green-House Gas
- GLAS Geoscience Laser Altimeter System
- GLOSS Global Sea Level Observing System
- GMES Global Monitoring for Environment and Security
- GNSS Global Navigation Satellite Systems
- GOCE Gravity field and steady-state Ocean Circulation Explorer
- GOCI Geostationary Ocean Colour Imager
- GOME Global Ozone Monitoring Experiment
- GOMOS Global Ozone Monitoring by Occultation of Stars
- GOMS Geostationary Operational Meteorological Satellite (Russian Federation)
- GOOS WMO/IOC/UNEP/ICSU Global Ocean Observation System
- GOS Global Ocean Observing System
- GOS WMO Global Observing System
- GOSAT Green-house gaz Observing Satellite
- GPM Global Precipitation Measurement
- GRACE Gravity Recovery And Climate Experiment
- GRAS Metop's GNSS Receiver for Atmospheric Sounding
- GRUAN GCOS Reference Upper Air Network
- GSICS Global Space-based Inter-calibration System
- GSM Global System for Mobile Communications
- GSN GCOS Surface Network
- GTN Global Terrestrial Network
- GTN-G Global Terrestrial Network for Glaciers
- GTN-GW Global Terrestrial Network for Groundwater
- GTN-H Global Terrestrial Network for Hydrology
- GTN-P Global Terrestrial Network for Permafrost
- GTOS Global Terrestrial Observing System
- GTS WWW Global Telecommunication System
- GUAN GCOS Upper-air Network
- HEO Highly Elliptical Orbit satellite

- HF High Frequency
- HRFI High Resolution Fast Imagery
- HY-2A HaiYang ocean satellite mission (China) 2A
- IAGOS Integration of routine Aircraft observations into a Global Observing System
- IASI Infra-red Atmospheric Sounding Interferometer
- ICSU International Council for Science
- IGRAC International Ground water Resources Assessment Centre
- IOC Intergovernmental Oceanographic Commission of UNESCO
- IOS Integrated Observing System
- IRS Infra-red Sounder
- ISRO Indian Space Research Organisation
- ISS International Space Station
- ITU International Telecommunication Union
- IWV Integrated Water Vapour
- JASON Ocean Surface Topography mission (USA/France)
- JAXA Japan Aerospace Exploration Agency
- JCOMM Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
- LAI Leaf Area Index
- LAM Limited Area Model
- LANDSAT Earth-observing satellite missions (NASA/USGS)
- LDC Least Developing Country
- LEO Low Earth Orbit satellite
- MERIS MEd Resolution Imaging Spectrometer
- METEOSAT EUMETSAT Geostationary Meteorological Satellite
- Metop EUMETSAT Polar Orbiting Operational Meteorological Satellite
- MODIS MODerate-resolution Imaging Spectrometer (onboard AQUA and TERRA satellites)
- MSU Microwave Sounding Unit
- MTG Meteosat Third Generation
- MTM CNES/ISRO Megha-Tropiques Mission to observe the water cycle and energy budget in the tropics
- NASA National Aeronautics and Space Administration
- NMHS National Meteorological and Hydrological Services
- NMS National Meteorological Services
- NPOESS National Polar-orbiting Operational Environmental Satellite System (USA)
- NWP Numerical Weather Prediction
- OceanSites Ocean Sustained Interdisciplinary Timeseries Environment observation System
- OCS Ocean Colour Scanner on the Russian Meteor Satellite
- OLCI Ocean Land Colour Imager

OMPS Ozone Mapping and Profiler Suite

- OPAG Open Programme Area Group
- OPAG-IOS OPAG on the IOS
- OPERA Operational Programme for the Exchange of weather RAdar information
- OSE Observing System Experiment
- OSSE Observing System Simulation Experiment
- PALSAR Phased Array L-band Synthetic Aperture Radar
- PILOT FM-32 PILOT GTS format : Upper-wind report from a fixed land station
- PMO Port Meteorological Officer
- POAM Polar Ozone and Aerosol Measurement
- PROBA PRoject for OnBoard Autonomy
- PUMA Préparation à l'Utilisation de MSG en Afrique
- QA Quality Assurance
- QM Quality Management
- QMF Quality Management Framework
- QuickSCAT Quick Scatterometer (NASA)
- R&D Research and Development

- RA WMO Regional Association
-
- RBCN Regional Basic Climatological Network
- RBSN Regional Basic Synoptic Network
- RRR Rolling Review of Requirements
- SAR Synthetic Aperture Radar
- SARAL Environment monitoring mission (India/France)
- SBUV Solar Backscatter Ultraviolet Radiometer
- SCARAB Scanning radiative budget instrument onboard MTM
- SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmosphere Chartography
- Sentinel-3 A multi-instrument ESA satellite mission contributing to GMES
- SIA Seasonal to Inter-Annual
- SIDS Small Island Developing State
- SIRAL Synthetic Aperture Interferometric Radar Altimeter
- SLSTR Sea and Land Surface Temperature Radiometer
- SMOS Soil Moisture and Ocean Salinity
- SoG Statement of Guidance
- SPOT Satellite Pour l'Observation de la Terre
- SSH Sea Surface Height
- SSM-I Special Sensor Microwave Imager
- SSS Sea Surface Salinity
- SST Sea Surface Temperature
- SYNOP FM-12 SYNOP GTS format - Report of surface observation from a fixed land station
- TAMDAR Tropospheric Airborne Meteorological Data Reporting
- TEC Total Electron Content
- TEMP FM-35 TEMP GTS format - Upper-level pressure, temperature, humidity and wind report from a fixed land station
- TERRA Terra satellite mission - http://terra.nasa.gov/
- THORPEX The Observing system Research and Predictability Experiment
- TOPC Terrestrial Observation Panel for Climate
- TOMS Total Ozone Mapping Spectrometer
- TRMM Tropical Rainfall Measuring Mission
- UAV Unmanned Aeronautical Vehicle
- UNEP United Nations Environment Programme
- UNESCO United Nations Educational, Scientific and Cultural Organization
- USA United States of America
- USGS US Geological Survey
- UTC Coordinated Universal Time
- UV Ultra-violet
- VCP WMO Voluntary Cooperation Programme
- VSRF Very Short Range Forecasting
- VOS Voluntary Observing Ships Scheme
- WCRP World Climate Research Programme (WCRP)
- WHYCOS World Hydrological Cycle Observing System
- WIGOS WMO Integrated Global Observing System
- WIP WIGOS Implementation Plan
- WIS WMO Information System
- WMO World Meteorological Organization
- WWW WMO World Weather Watch
- XBT Expendable Bathythermograph
- ZTD Zenith Total Delay
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